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Optimal noise reduction due to correct material selection and design in Common-mode chokes

Abstract

When designing modern and often complex integrated systems, engineers must take into account the possibility of electro-magnetic interference, which affects the performance of the system and can lead to a failure to meet EMI regulatory standards.

The usual solution to these conducted emissions is to add a common mode choke (CMC) to the design. This allows the target signal to pass unaffected, whilst filtering out undesired signals.

It is important that reliable, functional and affordable materials are used in CMC components. This article discusses the need for CMCs, outlines the most often-used materials and introduces Nano-crystalline as an important material for existing and future CMC production.

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1. Definition of common mode choke (CMC)

CMC filters are designed in a way that the desired signal, also called differential mode current "I_{DMC}", flows through one winding and back through another winding in such a way that the magnetic flux densities "BDMC1"and "BDMC2"caused from the magnetic fields of the conductors are compensated inside the core.

This means that the desired signal is unaffected by the CMC and is therefore not causing signal degradation (shown in Fig.1a in blue).

The unwanted high frequency common mode noise "I_{CMN}"passes differently through the CMC in that the CMC is working as an inductor for the noise signals and therefore attenuating the noise (shown in Fig.1b in red).

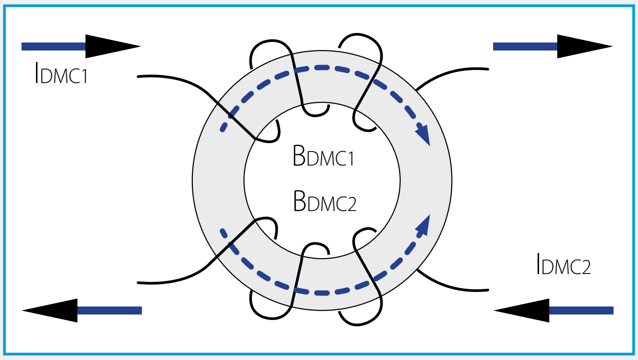

Fig. 1a. Simplified 1-phase CMC model with differential mode current (IDMC)

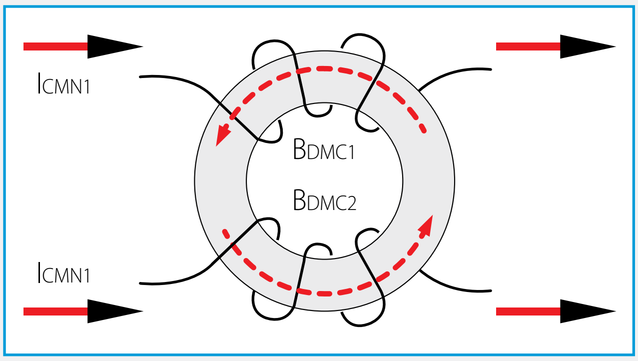

Fig.1b. Simplified 1-phase CMC model with common mode noice current (ICMN)

2. Material design criteria for an efficient common mode choke

The impedance is working against the noise as shown in the following formula:

$$Z(f, H_{ICMN}) = \omega * L(f, H_{ICMN})$$

$$Z(f, H_{ICMN}) = 2 * \pi * f * L(f, H_{ICMN})$$

Inductance is defined as followed:

$$L = AL * N^2 = \mu_0 * \mu_i * \frac{A_{fe}}{L_{fe}} * N^2$$

$$Z(f, H_{ICMN}) = 2 * \pi * f * \mu_0 * \mu_i * \frac{A_{fe}}{L_{fe}} * N^2$$

As seen in the above equation the CMC can influence the damping of the noise by three factors: initial permeability of the core material; core geometry and number of turns. These factors influence each other dramatically.

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2.1 Winding

Ideally, the windings of CMCs are wound in opposite directions on two sections of a non-gapped toroidal core. Depending on the wire insulation and the rated voltage there should be a distance of at least 3mm between the conductor terminals.

With higher isolation wires like TEX-E the distances can be negated, but this leads to a much higher wire price and less winding space due to the thicker insulation. Therefore, the design of a CMC should be realised with single- or double-enameled wires if possible.

Larger diameter wires have an important effect on the permeability of cores, as more strength is needed to wind the wire on to the core. This causes >6000µ mechanical stress, especially on high permeability cores, and therefore results in a reduction of permeability. This causes a reduction of the AL-Value and therefore a reduction of the inductance and impedance.

$$AL = \mu_0 * \mu_i * \frac{A_{fe}}{L_{fe}}$$

It is not only the winding stress that has an influence on Impedance; the pressure from gluing, for example with Epoxy, to a base plate or full/half potting into a housing has an effect that should not be ignored too, as seen in Fig.2

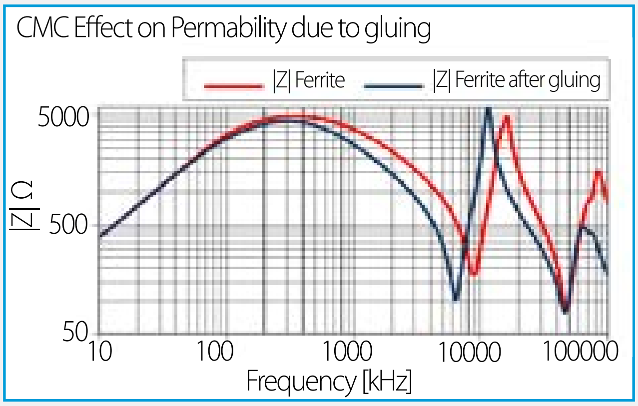

Fig.2. Gluing effect on high permeability cores

Furthermore, the design should have as few turns as possible to reduce price, conduction losses and to realise a one-layer winding. Multilayer windings lead to higher capacitive effect and therefore lower noise reduction in higher frequencies as seen in Fig.3.

It is shown that a high permeability material can reduce winding costs and part size, and increase the filter performance of a CMC.

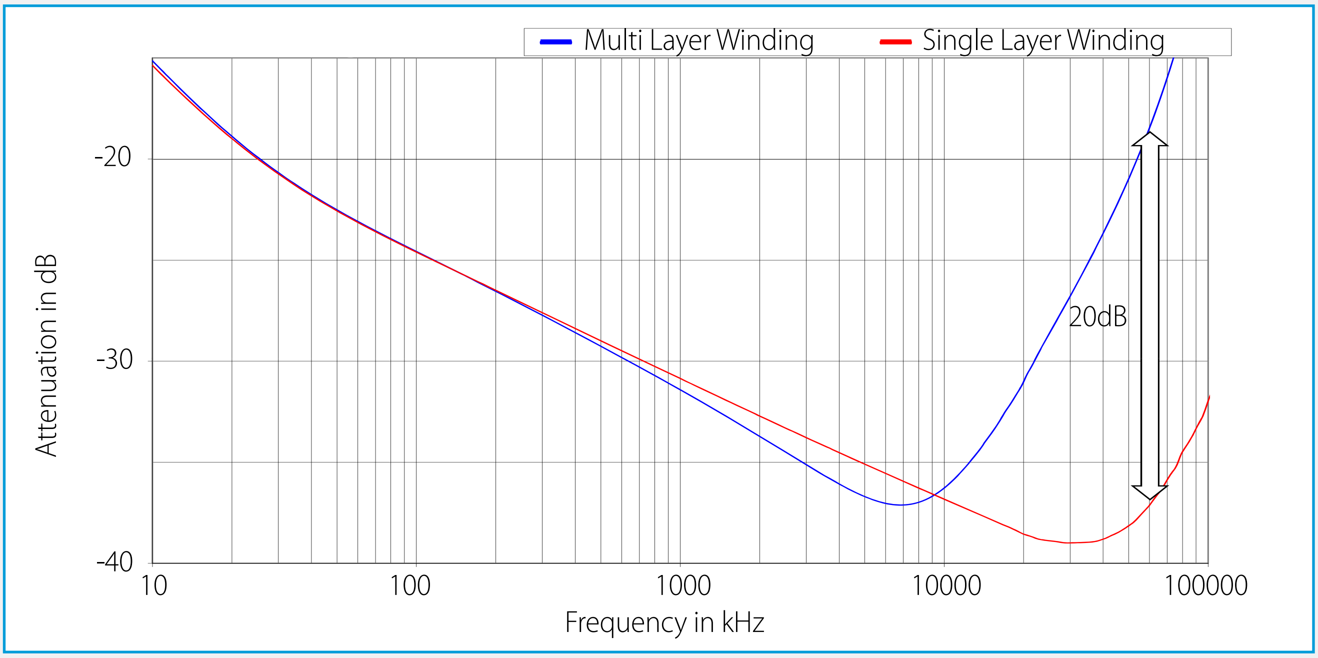

Fig.3. Effect of different windings on noise suppression (Nano-Crystalline Core: B FT-AY-302306; Turns: 2x 24; Wire: 1mm; Attenuation @ R=50 Ohms)

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2.2 Magnetic core materials used for CMCs

This section covers the soft magnetic core materials with high permeability that are suitable for CMC applications.

2.2.1 Ferrite

The most-used soft magnetic material is Ferrite. It is one of the first soft magnetic materials and therefore well-known and understood by developers. It is very hard, brittle and chemically inert.

The general composition of these types of ferrites is $MeFe_2O_4$ where Me represents one of several transition metals. The most popular combinations are manganese and zinc, or nickel and zinc.

Manganese and zinc ferrites have higher initial permeability (µi) and saturation inductions levels (Bs), and are suitable up to 3 MHz. They are often used in power inductors and transformers, as well as in filter applications like CMCs.

Nickel and zinc ferrites have a very high resistivity and are most suitable for frequencies over 1 MHz. They are most frequently used for low-current and high-frequency applications such as wideband EMI suppression and transformers, and balun transformers.

The main advantage of ferrites over other magnetic materials is the high volume resistivity of the material.

Considering the two main core loss factors, the hysteresis losses $Ph \sim f * B^2$ and the eddy current losses $Pe \sim f^2$, they depend on the peak magnetic flus density B and the frequency f.

At high frequencies the flux density will decrease and the eddy current losses will exponential increase. These losses are inversely proportional to the resistivity of the used material.

Ferrites with their high resistivity are therefore ideally used in high frequency magnetic components.

This article will discuss MnZn ferrite materials with high initial permeability like the Magnetics W-Series (µi=10,000) and Ferroxcube 3E-Series (µi up to 20,000).

Typical Ferrite material impedance behavior over frequency is shown in Fig.4 curve μ_s''.

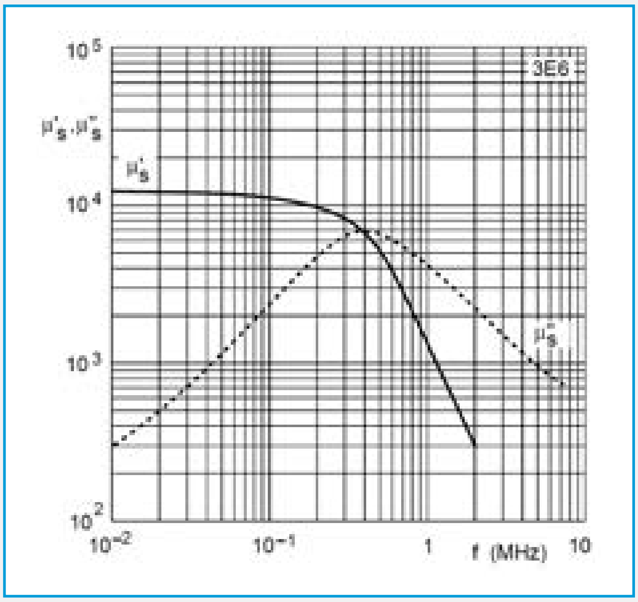

Fig.4. Complex permeability as a function of frequency for FXC 3E6 ferrite material

The graph shows nicely that the highest filter behaviour is in a small bandwidth. A ferrite CMC should be designed to the specific noise frequency. If this is done no other material can be more useful than a ferrite.

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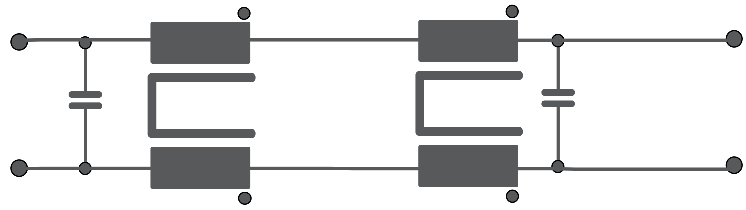

Fig.5. Two-Stage EMI filter with CMCs for LF and HF noises

With multiple noises in, for example, low frequencies(LF) and high frequencies (HF) there have to be multiple ferrite CMCs and therefore multiple filter stages. In this case other material solution should be considered.

The temperature dependency of Ferrite materials should be considered carefully before start designing. The permeability can change in different temperature ranges and therefore noise filtering behavior.

Some of the latest materials like Ferroxcube 3C95 and 3C97 Series are more temperature stable, but they do not have enough permeability to be used for CMCs. The permeability has to be calculated in the working temperature.

For applications with a working temperature range, it is important to calculate the CMC for the whole range. If this does not happen, the device may pass at one temperature and fail for another.

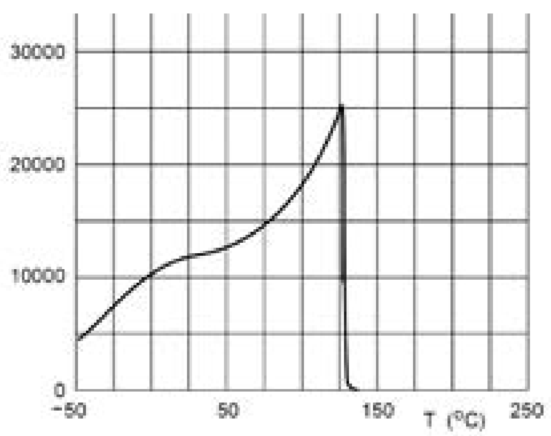

Fig.6. Initial permeability as a function of temperature of FXC 3E6 material

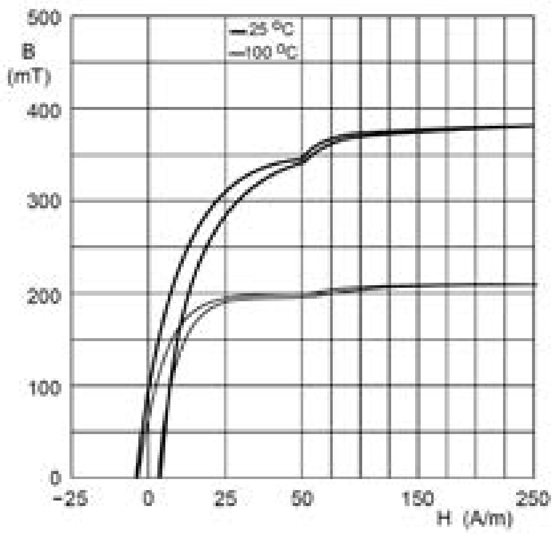

Fig.7. Typical B-H loops of FXC 3E6

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2.2.2 Nano-crystalline

Nano-crystalline material is made of iron-based amorphous tape. The random atomic structure of amorphous material is partly re-crystallised in microscopically small areas. This is done with a highly controlled heat treatment between 500°C and 600°C.

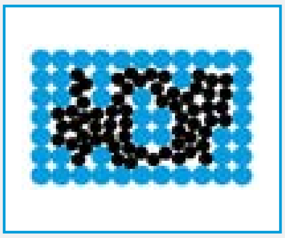


Fig.8. Nano-crystalline structure

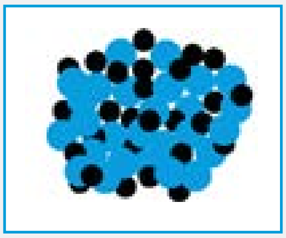
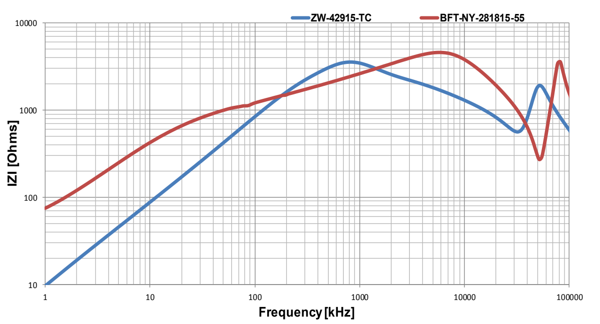


Fig.9 . Amorphous structure

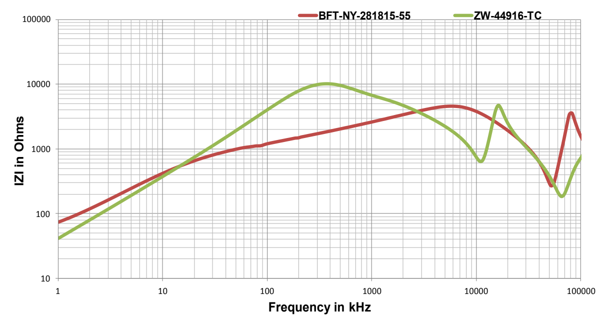
Nano-crystalline chokes show good wideband noise filter behavior due to the very high permeability up to 150.000. The high permeability leads to fewer turns and results in lower winding costs, smaller size, lower conduction losses and reduction of capacitive effects.

The benefits can be seen in direct comparison to a Ferrite choke in Fig. 10 and Fig. 11.



Ferrite	Nano-crystalline
30x18x15mm	30x18x16mm
L = 1560µH	L = 5500µH
N = 2x 10	N = 2x 11
AL = 12.900nH	AL = 55.000nH

Fig.10. Comparison between ferrite and Nano-crystalline CMC



Ferrite	Nano-crystalline
49x34x16mm	30x18x16mm
L = 5500µH	L = 5500µH
N = 2x 22	N = 2x 11
AL = 18.000nH	AL = 55.000nH

Fig.11. Comparison between ferrite and Nano-crystalline CMC

Nano-crystalline cores offer a wideband filtering behavior compared to ferrite as seen in Fig. 10 and Fig. 11.

For LF and HF noise, it is possible to use one Nano-crystalline CMC instead of several ferrite CMCs. These reduce component cost and PCB real estate.

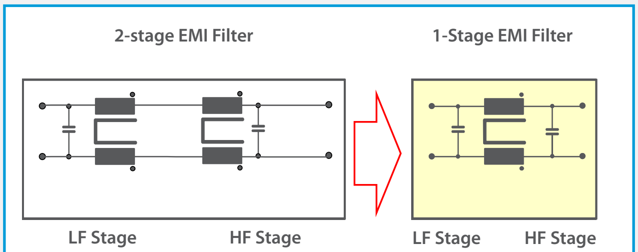


Fig.12. Reduction of filter stages with Nano-crystalline cores

Compared with ferrites, Nano-crystalline material has a constant permeability over a wide temperature range. This gives a huge benefit to applications requiring operation over a wide temperature range.

3. Conclusion

This article shows that it is important to know the noise level of the device in order to design the right CMC. The following table summarises the main points.

Attributes	Ferrite	Nano-crystalline
Single peak noise	+	O
Wideband noise	O	+
Permeability	O	+
Temperature stable	O	+
Core price	+	O
Part size	O	+

Tab.1. Material comparison

Ferrites are the best solution for high-peak noise frequency reduction in a small bandwidth. Where operational temperature is either constant or varies over a narrow range.

Nano-crystalline materials with their high permeability, temperature stable behavior and low losses are ideal for noise reduction in a wider bandwidth or where no high peak noise frequencies appear. They are especially suited to applications where large temperature deviations exist in normal operation.

At Acal BFi we can supply you with a wide range of soft magnetic cores, including ferrite and Nano-crystalline, for your project alongside a range of services to support you from start to finish.

Our design team has more than 25 years' experience and can support you with the design of common mode chokes using ferrite and Nano-crystalline cores. From arranging manufacturer samples to ordering and holding production stock on your behalf, we work with you to ensure your design is successful.