The following was written primarily for industrial Electrical Design Engineers but the fundamentals are the same for RF systems such as those used by amateur radio operators.

Source: Academy of EMC

Inductors in EMC - Common-mode noise filtering

This article introduces magnetic components for common-mode noise filtering:

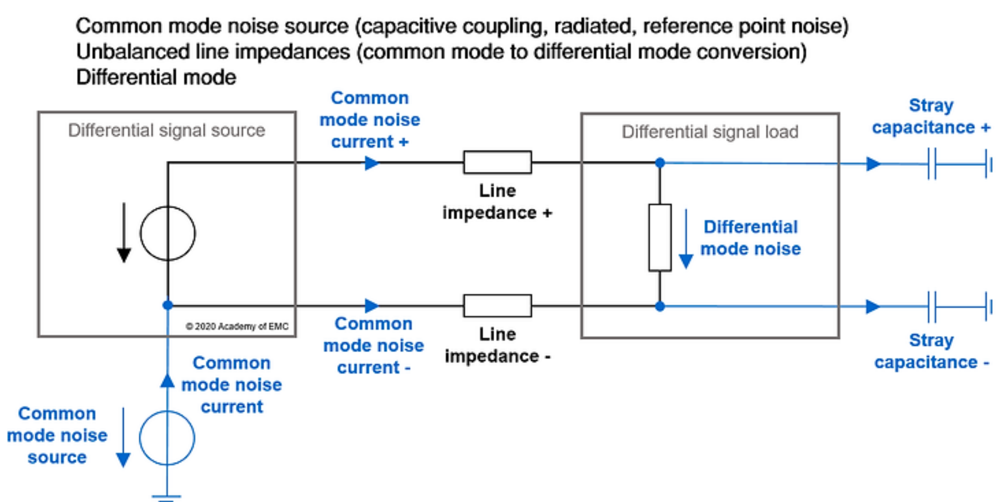
- Clamp ferrites (cable ferrites)
- Common-mode chokes

Both are widely used in the field of electromagnetic compatibility (EMC) to filter common-mode noise. This article presents common-mode noise filtering fundamentals, characteristics and some real applications.

What is common-mode noise?

Common-mode noise is one of the most common sources for radiated emission. The characteristics of common-mode noise can be seen in the picture below: a common-mode noise current flows through the signal forward AND through the return signal path in the SAME direction. There are different sources of common-mode noise, such as capacitive coupling (simultaneously to the forward and return current signal path) or a noisy reference point. There are two effects that might occur when common-mode noise is present:

- Radiated emissions caused by unintended antennas (e.g. long cables).
- Differential-mode noise caused by unbalanced lines (common-mode to differential-mode conversion).



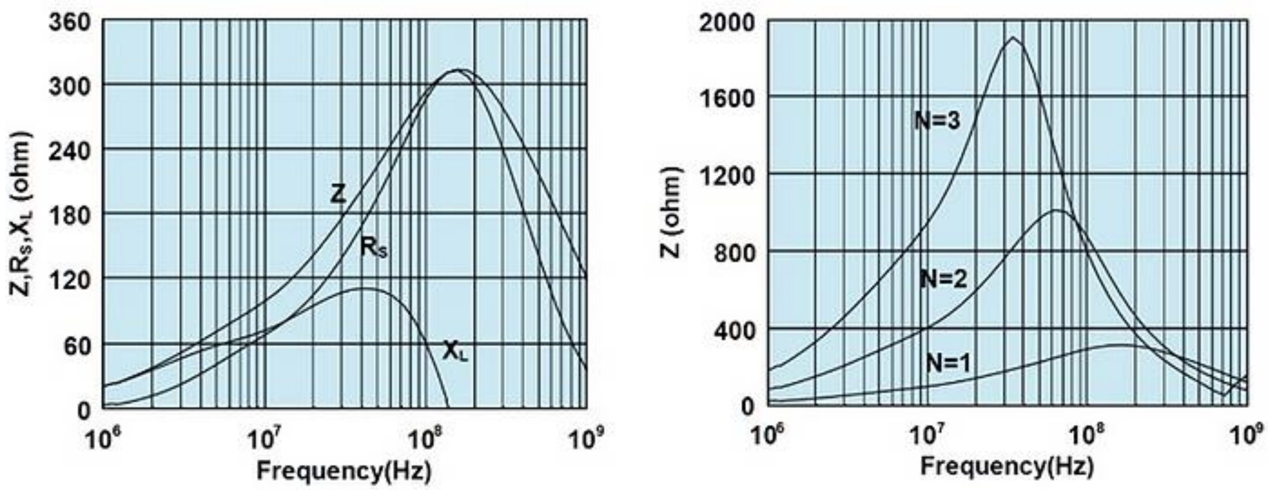
What are clamp ferrites?

Clamp ferrites – also called cable ferrites – are those that can be opened and installed around a wire or a cable. They are very convenient because it is possible to install them around wirings without the need of disconnecting any terminal. Clamp ferrites are made of high magnetic permeability materials such as MnZn or NiZn. The high permeability of these materials “forces” a concentration of the magnetic field lines of the common-mode current within these clamp ferrites.

Example of a clamp ferrite (cable ferrite)

Characteristics of clamp ferrites

From a physical standpoint, clamp ferrites work as ferrite beads. They have a frequency dependent impedance. With increasing frequency ferrite beads behave inductive, until the frequency reaches the resonance frequency. Around the resonance frequency, a ferrite bead behaves resistive and therefore helps to suppress common-mode noise effectively. For even higher frequencies, a ferrite shows capacitive behavior. The next two figures show a typical frequency response of a clamp ferrite. The left graphic shows how the impedance varies with frequency (resonance frequency of approximately 150 MHz). The second one shows how the resonance frequency changes with the number of turns, i.e. how many times a cable is wound around a ferrite. When adding turns the impedance increases, but the frequency shifts because of the extra capacitance.



Characteristics of a ferrite clamp.

Main parameters of clamp ferrites

Clamp ferrites come in a variety of types and sizes. To select the appropriate one, it is fundamental to know some main aspects:

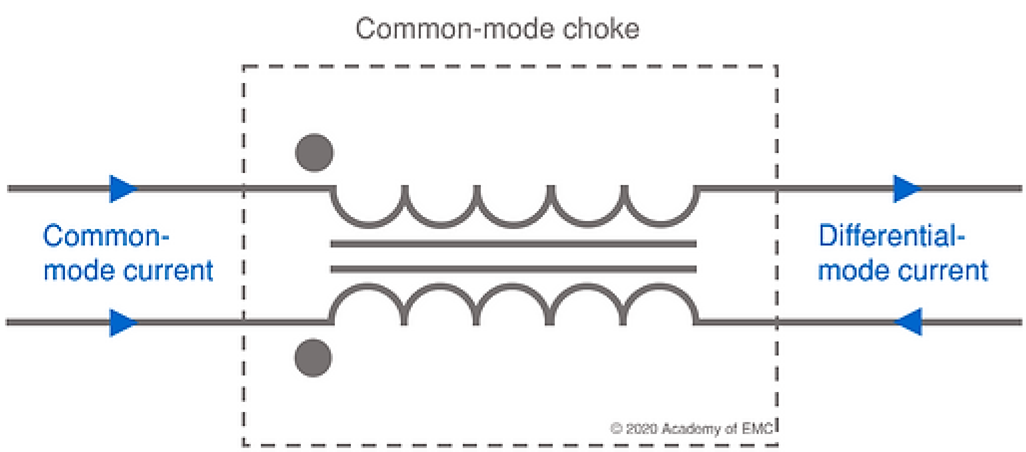
- **Material.** The magnetic material and its permeability will determine the useful frequency range of a ferreit. There are many types of materials. Here the most important ones: Iron-powder (Fe), suitable for low frequencies. MnZn cores, suitable from several MHz up to 30 MHz. NiZn, suitable from several MHz up to 1 GHz.
- **Curie Temperature Tc.** Magnetic materials keep their properties until they reach the Curie temperature value. For higher temperatures, a ferrite loses its permanent magnetism, and therefore loses all the filtering capabilities. Usually, the temperatures values are high, of several hundreds of [ºC]. Usually, the Curie point is much higher than the recommended operating temperature, so ferrites should never be working around that high temperatures. As an example, Würth Elektronik claims Tc of some ferrites to 150ºC.
- **Size.** The maximum wire size that can be inserted through a ferrite and the number of turns.
- **Saturation.** Like other parts made out of ferromagnetic materials, clamp ferrites change its behavior with increasing current. However, common-mode currents – which are responsible to suppress unintended radiated emissions – are usually in the range of micro- or milliamperes. Therefore, saturation current is usually not an issue for cable ferrites as common-mode electromagnetic interference (EMI) filters.

What are common-mode chokes?

Common-mode chokes, also known as current compensated chokes, are basically a pair of coupled inductors.

SMD Common-mode Choke.

The figure below shows how the differential and common-mode currents flow through a common-mode choke. The differential-current circulating through each of the inductors creates a magnetic field and, since they are coupled, the magnetic field created by one inductor opposes the one created by the other inductor, then eliminating the common magnetic energy circulating for both conductors.



Common-mode choke symbol.

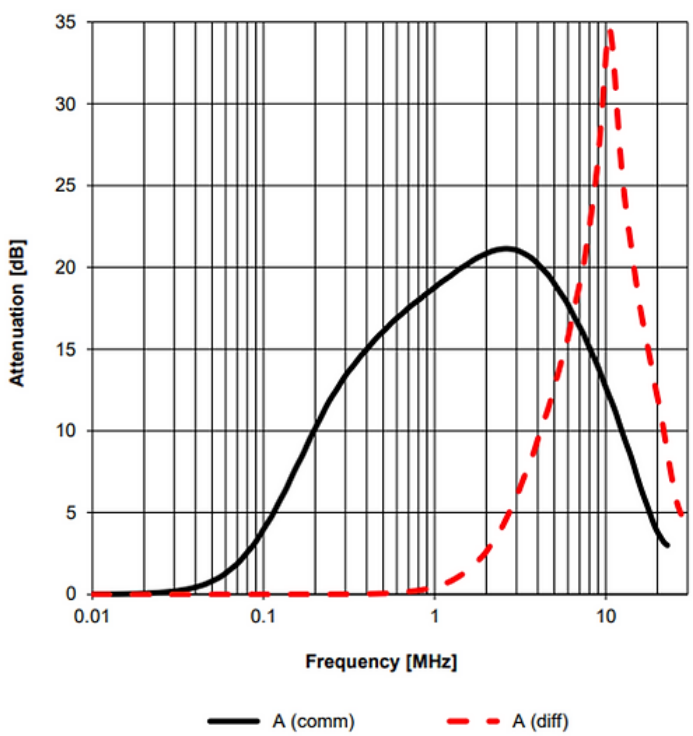
Characteristics of common-mode chokes

An ideal common-mode choke eliminates all the common-mode noise (infinite common impedance) and will let all the differential signals pass through it (null differential impedance). In real world, there are limitations with both characteristics, so it is important to know the application and its frequency characteristics to choose the right choke.

As introduced before, the impedance presented to common-mode signals is known as common impedance, while the one presented to differential signals is known as differential impedance. The measure of both parameters can be done using a network analyzer. For each of the frequency response measurements, inputs and outputs of common-mode chokes need to be short-circuited as follows shown in the picture below.

Left: common-mode measurement. Right: Differential-mode measurement.

Datasheets usually include curves with both common-mode and differential-mode impedances and they are normally indicated in logarithmic scale [dB], providing information about the attenuation they produce to common-mode and differential-mode signals circulating through chokes.



Common- vs. differential-mode attenuation of a common-mode choke

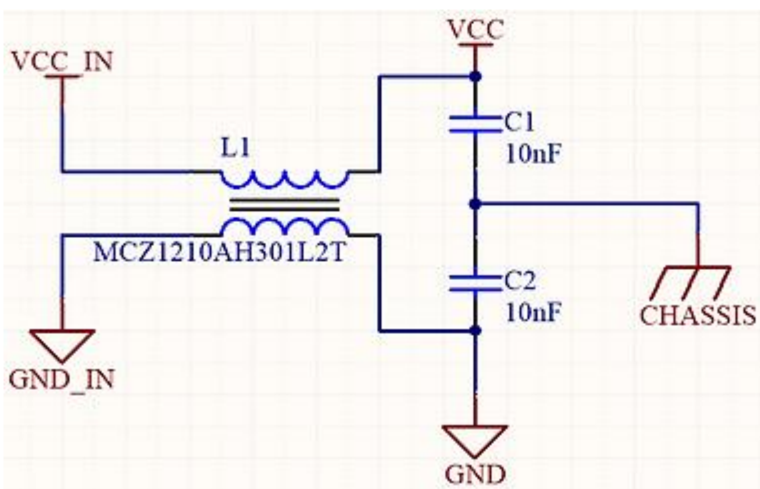
Main parameters of common-mode chokes

When selecting a common-mode choke, the most relevant parameters to consider are the following:

- **Current rating [A].** Maximum root mean square (RMS) current that can be applied without saturating the core. Leaving some room for the maximum saturation current is crucial to avoid core saturation. However, common-mode currents – which are responsible for unintended radiated emissions – are usually in the range of micro- or milliamperes. Therefore, saturation current is usually not an issue for common-mode electromagnetic interference (EMI) filters. The limiting factor for the current rating of common-mode chokes is the copper resistance Rdc of the windings, because this leads to thermal heating of the choke.
- **Material.** Core material will determine the frequency band as well as the saturation limits. The magnetic permeability μr [1] describes the capacity of concentration of the magnetic flux in the material.
- **Direct current resistance Rdc [Ω].** Maximum resistance at 0 Hz. It is caused by the fact that every copper wire has a resistance which is greater than 0 Ohm. It will determine the maximum power losses of the common-mode choke.
- **Nominal inductance [H].** It is normally given with the test under which the inductance has been measured (frequency and applied current). That is why attenuation curves are not completely flat and the reason why there is a self-resonance.

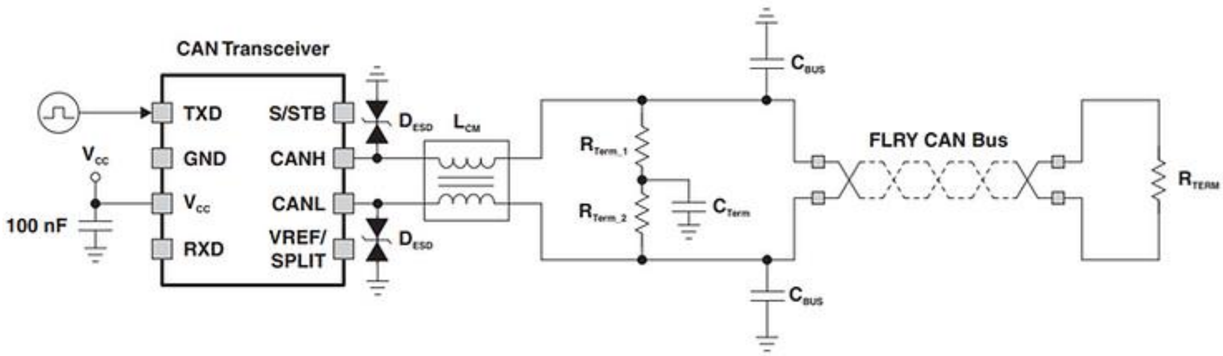
Real applications

Common-mode chokes are frequently used to filter the power input lines. In that case, the common-mode choke attenuates noise which comes from the external power supply and vice versa.



DC power line filter with common-mode choke.

In differential communication buses – such as the Controller Area Network (CAN), widely used in automotive – common-mode chokes filter the signals before being carried to other parts of the vehicle.



Common-mode filter in a CAN bus communication

In high-speed applications, such as Universal Serial Bus (USB), it is common to add a ferrite bead to one end or even both ends of the cable. It is usually done to avoid unintended radiation by attenuating the common-mode currents through the cable.

Ferrites over a USB cable

Conclusion

Clamp ferrites and common-mode chokes are critical components in the field of electromagnetic Compatibility (EMC). They attenuate high-frequency common-mode noise currents and therefore help to keep radiated emissions low. Clamp ferrites are widely used for troubleshooting purposes since they can be easily installed in a system which is already assembled. Common-mode chokes are important to suppress common-mode noise in power-supplies and high-speed differential signal lines (e.g. CAN, Ethernet, LVDS) and RF communications systems.

This blog post was written by Ignacio de Mendizábal (electronics engineer, Brussels) and edited by Reto Keller (electronics engineer, Switzerland). Many thanks to Ignacio and Reto for their valuable work.

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