Ferrites as simple EMI filters – Notes Rev 1.1 12/2023
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Ferrite beads are useful for many EMC filter uses. In simplified terms, ferrites behave as short circuits at low frequencies and as low Q inductors at high frequencies. They behave like capacitors at much higher frequencies.

The core material is very lossy in the intended operating frequency range, which makes then act more like resistors than inductors in their prime operating ranges. This means that as opposed to typical LC filters, they absorb energy rather than just redirecting it.

Typical surface mount ferrite beads have impedances in the range of 30 to 1000 ohms in their operating frequency range. Material and design affect the frequency range and impedance range. In general, ferrite beads are most effective above 30 MHz and most have peak effectiveness in the range of 100-200 MHz. Some ferrites can operate effectively at lower frequencies and some up to 1 GHz or more.

Ferrite Beads are used to:

- Provide series resistance in a signal or power line.
- Act as the series element in a low pass filter (L, Tee, or Pi).
- Add damping to potential circuit oscillations (such as FET gate circuits or switching supplies)
- Add the equivalent of a resistance at high frequency while acting as a short at low frequency.
- Etc.

In Filters:

Surface mount ceramic capacitors are effectively used in simple low pass filters as the shunt element with ferrite beads as the series element.

Example:

Ferrite Bead Impedance:

- 0.2 Ω at DC to 100 KHz
- 10 Ω at 10 MHz
- 100 Ω at 100 MHz
- 40 Ω at 400 MHz

*With a 1000 pF Ceramic Capacitor shunt element (to GND plane):

- 1600 KΩ at 100 KHz, Atten = 0dB
- 16 Ω at 10 MHz, Atten = 4dB
- 1.6 Ω at 100 MHz, Atten = 36 dB
- 0.4 Ω at 400 MHz, Atten = 40dB

*Idealized -- assuming no parasitic inductance or capacitance. Actual is less.

Ferrites on cables

The familiar clamp-on ferrite beads are often added during EMI testing to gain a few dB. These are useful tools for troubleshooting and remediation at this stage, but there are limitations.

First, it is difficult to get more than 2-4 dB improvement in radiated emissions with a single clamp-on ferrite. This is because the clamp-on ferrites don't have enough impedance at the frequency of interest given the other series impedances and the load impedance (of the cable). The load impedance of the cable at the frequency of interest may be a few hundred ohms, and is highly dependent on terminations and frequency. If the ferrite adds 60 ohms and the load impedance is 300 ohms that's 1.6 dB. If the ferrite has adds 250 ohms, that's 5.3 dB. If the source impedance is already high, even a higher impedance ferrite may have little effect.

Try another turn or two

The impedance of a clamp on ferrite will go up approximately with the square of the number of turns. One turn is straight through, and that's where most people stop. Running the cable back through the ferrite once more (that's 2 turns) can increase the impedance by a factor of 4. Three turns is a factor of 9. This neglects stray capacitance, but it's clear that 2 or 3 turns can increase the effectiveness, if there is enough room in the ferrite core opening for the cable to pass through a couple of times. The frequency of peak attenuation is also lowered with multiple turns.

Beware that the current in the core also goes up with turns and the risk of core saturation thus goes up as well.

Common Mode Noise

Radiated noise from cables is most often common mode, meaning that all the wires in the cable are carrying the same noise current in the same direction. This is why placing the ferrite around the entire cable can reduce the radiated noise, as it increases the *common mode* impedance.

When clamped around all wires in the cable together, the ferrite acts as a common mode choke. When clamped on a single wire of the cable, the ferrite oppose normal (differential) mode current, and will be more likely to saturate.

The Material Matters

Ferrites are constructed out of a variety of materials and each vendor has their particular formulations. Various materials can be most effective in particular frequency ranges from under 1 MHZ up to 1GHZ or more.

Here are some popular materials and approximate frequency ranges:

Fair-Rite Manganese Zinc:
- 31 (1-300M)
- 73 (< 50M)
- 75 (< 20M)

- 76 (< 5M)
- 77 (< 10M)
- 78 (< 10M)

Fair-Rite Nickel Zinc:

- 15 (10-300M)
- 20
- 43 (25-300M)
- 44 (25-300M)
- 51 (50-500M)
- 52 (50-1000M)
- 61 (200-2000M)

Fair-Rite Magnesium zinc:

- 46 (25-300M)

Laird LF (0.7-30M)
Laird 28 (5-1000M)
Laird HF (100-2000M)

Wurth Electronics also makes many ferrites and has very good technical information available.

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