Application Note

EMC/EMI Filter Design with RB Common-Mode Chokes: Part 1

www.schaffnerusa.com

shaping electrical power

Content

Scope of this Application Note

This two-part application note addresses experienced engineers, who are familiar with the basics of EMC.

- Part One will provide an in-depth review of the RB choke series and the benefits of its unique design.
- Part Two will provide a theoretical approach to determining how much EMC noise is present in your design, and how to calculate and create the correct EMC filter to mitigate expected noise.

Introduction

With RB chokes, any DC, single- or three-phase EMC/EMI filter can be designed. Target applications are PV or drive inverters, welding units, quick chargers, power supplies or any other power electronic device.

RB choke series are common-mode (CM) chokes designed for a current range from 16A to 50A with convection cooling. They can operate with currents up to 80A in forced cooling areas with 3m/s air velocity. Integrating EMC/EMI filters directly into the power unit results in higher power density.

Like most Schaffner EMC/EMI filters, RB chokes match for worldwide applications. Bobbins and base plates consist of halogen free plastics. All materials are in accordance with the new ROHS and REACH requirements for products for the European Community and fulfill the specifications for UL approval.

More technical details can be found in the RB series datasheet.

RB chokes can be disassembled after end of life, helping to fulfill the recycling quota required in directives like "Waste Electrical and Electronic Equipment" or similar documents advising on the "green" design of electronic equipment.

Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI)

The main task of the EMC/EMI filter design is to bring EMI noise down below the allowed limits of emission standards for the conducted RF range. For more details please refer to the Application Note Basics in EMC and PQ.

EMC/EMI filter design

To fulfill the generic standards for conducted emissions, EMI noise has to be reduced starting from 150 kHz. In some products standards like for lighting products the limits start at 9 kHz.

RB chokes are so-called common-mode (CM) or current-compensated chokes. They are wound with at least two identical windings. The current draw flows through both windings, causing magnetic flux in the opposite direction, resulting in almost zero inductivity. Due to the resulting flux of the currents being zero, the choke will not go into magnetic saturation under normal operating conditions.

High inrush currents, high crest factors (peak to average current ratio) of the line current draw, DC currents in only one winding as a result of unbalances (like small differences in switching times), or high frequency CM currents can cause saturation and degrade the proper operation of the EMC/EMI filter.

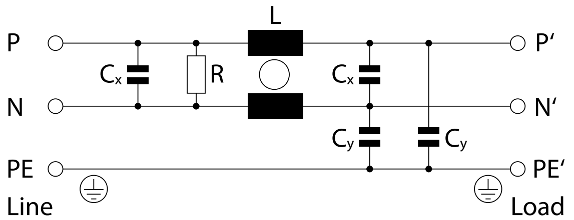


Fig 1: Schematic of a typical single-phase EMC/EMI filter

A typical EMC/EMI filter schematic is shown in figure 1. Designing filters with RB chokes is an economic way to combine low losses, low voltage drop, and minimal signal impact with efficient EMC/EMI filtering.

Although RB chokes are common-mode chokes, they can be used in EMC/EMI filter designs to mitigate both common-mode (CM) noise and differential-mode (DM) noise, because L consists of two parts: the nominal inductivity L_N and the stray inductivity L_S.

CM noise is damped by the nominal inductivity L_N of the choke and by the load-side C_Y capacitors to ground. DM noise is attenuated by the load-side capacitor C_X (if present) and the low pass filter consisting of the stray inductivity L_S of the CM choke (about 1% of L_N) and the line-side C_X.

The path via the Y-caps to PE (protective earth) closes the loop of CM current noise. The return path to the noise source has to be short for good CM attenuation performance.

The line-side PE connection is a safety measure. Here the leakage current flows with line frequency via the Y-caps. Line-side leakage current has to comply with the limits of applied safety standards (Refer to Application Note: **"Leakage current of power line filters"**).

The resistor on the line side is also a safety measure. It discharges the filter capacitors to ensure that the voltage on the terminals tends to zero after line voltage is switched off.

Design notes for RB chokes

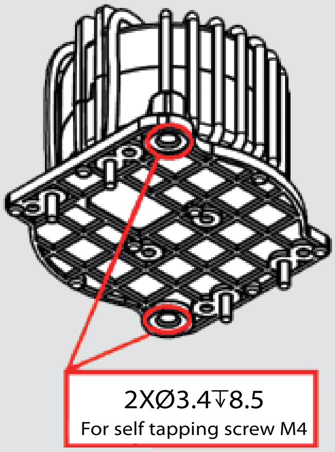


Fig. 2: RB choke mounting

RB chokes are designed to integrate EMC/EMI filters directly to the PCB. All RB chokes can be used for DC or AC applications ranging from 0 to 400 Hz line frequency. The chokes are designed with ferrite cores and can handle switching frequencies up to several hundred kHz.

Cores are enclosed by bobbins with clearance (cl) and creepage (cp) distances (all 2 wire versions cl >3.6 mm, cp >5.2 mm; all 3-wire chokes cl >5.5 mm, cp >6.4 mm). This is to fulfill product-related safety requirements and to ensure long term reliability, even under severe operating conditions like vibration or thermal fluctuation.

RB chokes offer screw domes allowing them to be mounted directly to the PCB for additional mechanical strength.

Because of the clear winding separation, RB chokes can also be used for HF transformer applications.

Low and high inductance versions

RB chokes are available in two inductance versions. The low inductance versions (all RB6xxx types) are suited for applications with high inrush current or high crest factor like power electronics with passive rectification not having sinusoidal line current draw. They can also be used for equipment with sinusoidal current draw.

The high inductance versions (all RB8xxx types) have a more pronounced attenuation, but a lower peak current ability and are thus recommended for applications with sinusoidal line current draw. For applications with higher EMI noise level or where EMI limits start earlier (e.g. lighting products), RB8xxx types can be used.

Vertical and horizontal versions

The low inductance series are available as vertical (all RB65xx types) and horizontal (all RB61xx types) versions. The high inductance series are available as vertical (all RB85xxx types) versions.

2-wire and 3-wire versions

For DC and single-phase applications, 2-wire CM chokes (all RBxx22 types) are offered., For 3-phase applications, 3-wire versions (all RBxx32 types) are offered. 4-wire versions are available on request.

Fig. 3: RB choke versions

Saturation

CM currents flowing through one or more windings without cancelling the flux to zero (limit ICM_{max}) or high peak currents running in differential-mode through both windings (limit IDM_{max}) like an inrush current can cause saturation. Table 1 shows the limits specified at 25 °C and 100 °C ambient temperature:

Designation	convection cooling nominal current I@60 °C [A]	forced cooling 3 m/s nominal current I@60 °C [A]	Nominal Inductance L_N@25 °C [mH/path]	Typical stray Inductance L_S@25 °C [µH/path]	Resistance R@25 °C [mΩ/path]	max. DM peak current 25 °C IDM_{max}@25 °C [A]	max. DM peak current 100 °C IDM_{max}@100 °C [A]	max. CM peak current 25 °C ICM_{max}@25 °C [A]	max. CM peak current 100 °C IDM_{max}@100 °C [A]
RB6122-16-1M0	16	25	1.00	6.3	4.8	135	95	0.24	0.16
RB6122-25-0M6	25	39	0.64	4.0	2.7	160	112	0.31	0.21
RB6122-36-0M5	36	53	0.45	3.6	1.5	185	130	0.41	0.28
RB6122-50-0M3	50	80	0.25	1.8	0.9	270	189	0.58	0.40
RB6522-16-1M0	16	25	1.00	6.2	4.6	135	95	0.24	0.16
RB6522-25-0M6	25	39	0.64	3.9	2.6	160	112	0.31	0.21
RB6522-36-0M5	36	53	0.45	3.6	1.5	185	130	0.41	0.28
RB6522-50-0M3	50	80	0.25	2.0	0.9	270	189	0.58	0.40
RB8522-16-3M0	16	25	3.00	22.2	8.4	73	51	0.17	0.11
RB8522-25-2M0	25	39	2.00	13.6	4.2	126	88	0.27	0.18
RB8522-36-1M5	36	58	1.50	12.8	3.0	165	116	0.40	0.27
RB8522-50-0M8	50	83	0.75	6.5	1.7	225	158	0.55	0.36
RB6132-16-0M8	16	26.5	0.80	5.8	4.6	155	109	0.32	0.22
RB6132-25-0M5	25	41	0.47	3.3	2.4	225	158	0.41	0.28
RB6132-36-0M4	36	60	0.42	2.9	1.4	330	231	0.59	0.39
RB6132-50-0M2	50	81	0.18	1.9	0.9	335	235	0.88	0.59
RB6532-16-0M8	16	26.5	0.80	6.9	4.7	155	109	0.32	0.22
RB6532-25-0M5	25	41	0.47	3.6	2.4	225	158	0.41	0.28
RB6532-36-0M4	36	60	0.42	4.2	1.5	330	231	0.59	0.39
RB6532-50-0M5	50	81	0.18	1.5	0.8	335	235	0.88	0.59
RB8532-16-1M3	16	27	1.30	9.1	5.7	128	90	0.26	0.17
RB8532-25-0M9	25	41	0.94	6.7	3.0	195	137	0.39	0.26
RB8532-36-0M8	36	58	0.83	7.3	2.3	260	182	0.55	0.36
RB8532-50-0M3	50	82	0.33	3.1	1.2	395	277	0.88	0.59

Table 1: RB chokes saturation parameters

ICM_{max} is the maximum allowed noise current flowing through one winding without causing saturation. IDM_{max} is the maximum allowed current flowing back and forward through both windings without causing saturation. These unbalanced situations should be kept below thresholds. For applications with ambient temperatures >125 °C, different core types can be optionally used.

Inductivity

The nominal inductivity of the RB chokes given in the datasheet is tested with a frequency of 1 kHz. CM chokes inquiries are often reduced to the inductivity value and ampere rating. Differences of core material and the inductivity test frequency have to be considered to achieve similar EMI attenuation results. The inductivity of a toroid choke can be calculated according equation 1:

$$L = \frac{\mu_0 \mu_r N^2 A}{2\pi r}$$

L	inductivity	N	number of turns
μ_0	magnetic constant	A	cross sectional area
μ_r	relative permeability	r	toroid radius to centerline

Equ. 1: Inductivity of chokes with toroid cores

Equation 1 shows that the inductivity depends on the number of turns, geometrical properties and on the relative permeability. The relative permeability is not constant over the frequency and has a different trend depending on the material. To compare inductivity values of chokes the relevant frequency range has to be determined first.

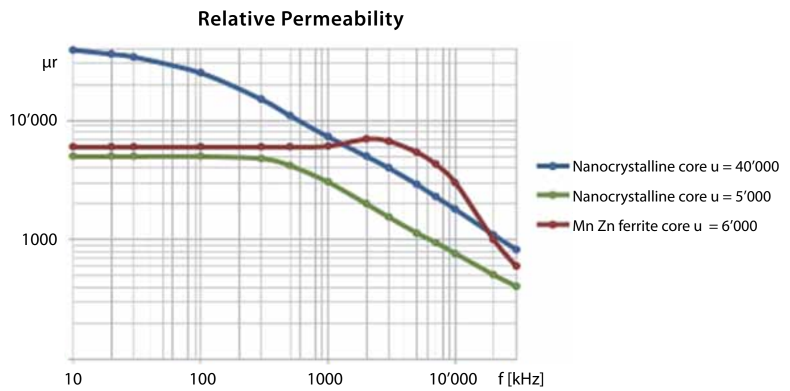


Fig. 4: Relative permeability μ_r for Mn Zn ferrite compared with nanocrystalline material

Figure 4 shows the relative permeability μ_r over the frequency for Mn Zn ferrite (displayed in red) used in RB chokes in comparison to nanocrystalline cores with a relative permeability of 40 000 (blue) and 5000 (green) at 10 kHz. The μ_r of nanocrystalline cores declines earlier towards higher frequency, the type with the high permeability maintains not even 20 % of its nominal value at 1 MHz. The inductivity is proportionally dependent to the relative permeability and declines the same way.

CM chokes with high μ_r nanocrystalline cores have a better performance in the lower frequency range but also a lower saturation limit. Nanocrystalline cores with about the same geometry and similar μ_r value (displayed in green) have a higher saturation limit than Mn Zn ferrite cores, but μ_r declines earlier. Due to the good overall characteristic, Mn Zn ferrite fits best for most EMC/EMI filter applications.

Impedance Z

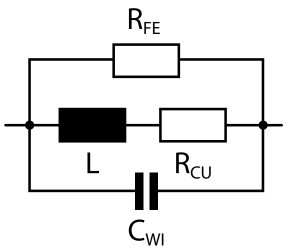
As shown before, L over f depends on several constant factors and the relative permeability. In theory, the impedance Z of an ideal CM choke would increase with the rising frequency according the equation 2:

$$Z = \omega L$$

ω angular frequency ($\omega = 2\pi f$)

Equ. 2: Impedance Z

A real choke has a parasitic winding capacitance (C_{WI}) as displayed in the simplified model in figure 5:



L inductivity
R_{FE} magnetic losses
R_{CU} copper losses
C_{WI} winding capacitance

Fig. 5: Simplified equivalent circuit diagram of a real choke

The impedance Z of a real choke rises until the resonance point is reached. The resonance frequency f_{res} depends on the parasitic winding capacitance (C_{WI}) and the inductivity L. It can be calculated according equation 3:

$$f_{res} = \frac{1}{2\pi\sqrt{LC_{WI}}} \quad \text{for } R_{CU} < 10\,\text{Ohm and } R_{FE} > 1\,\text{MOhm}$$

Equ. 3: Resonance frequency f_{res}

When the resonance point is reached, the trend of impedance Z as well as the attenuation will reverse and decrease. This can be seen in the following attenuation curves.

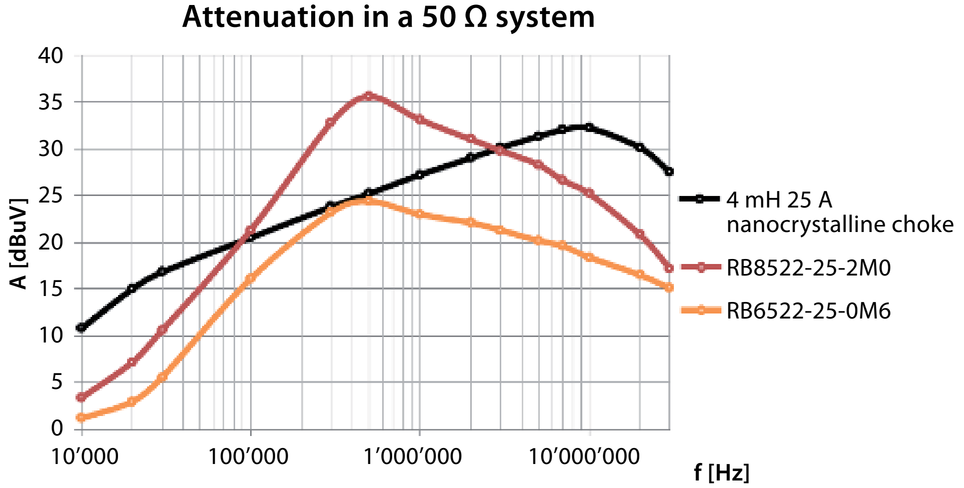


Fig. 6: Attenuation of RB6522-25-0M6, RB8522-25-2M0 and a 4 mH 25 A nanocrystalline choke

The attenuation curves in figure 6 show the performance of the 25 A high and low inductance version of RB series in comparison with a 4 mH 25 A nanocrystalline choke. As already seen in the trend of the relative permeability the nanocrystalline choke has a higher attenuation in the lower frequency area. It also has more attenuation in the higher frequency area due to less turns, resulting in a smaller winding capacitance.

Figure 6 also shows that RB chokes achieve a similar or better noise attenuation in the generic frequency range of conducted emissions with a nominal inductivity value 2 to 6 times lower than that of nanocrystalline chokes combined with a higher saturation limit. Due to the lower losses of ferrite cores, RB chokes can also be used for applications with higher switching frequency.

Stay tuned for part two of this application note. It will show a theoretical calculation method of expected EMC noise, as well as demonstrate how to calculate component values to be used in an EMC filter that mitigates expected noise.

SCHAFFNER EMC INC.
52 Mayfield Avenue
Edison, New Jersey 08837
+1 800 367 5566
+1 732 225 4789
usasales@schaffner.com
www.schaffnerusa.com

Product Types
Ecosine active
EMC/EMI
Power quality

Responsible For
USA
Brazil
Canada
Mexico