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Impact of component proximity coupling on EMC filter design

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Abstract

The EMC filter is an essential component in a module's design to ensure compliance with electromagnetic compatibility standards. The basic building blocks of any passive EMC filter consist of capacitors and inductors, which are used to mitigate electromagnetic interference. Often, these components have a large volume and create strong coupling to other bulky components placed nearby. This study focuses on the proximity of a metal body, such as a housing or other components, on choke inductance. Additionally, we have identified key parameters that influence the inductance performance and have proposed design guidelines to mitigate the effects of proximity field coupling.

1. Introduction

There have been studies focusing on the field coupling between chokes and it's effect on the filter performamce. Cuellar and Idir [1] have focused on the variation of inductance of Common Mode Chokes (CMCs) on filter attenuation. They have also proposed certain layout changes to mitigate the detrimental effect of coupling. [2-3] also present studies on the effects of 3D coupling on filter components with proposals to mitigate this effect. However, these works focus primarily on filter attenuation performance. In this work we primarily study the effects of 3D coupling of filters on the emissions arising out of an automotive module.

Most designers use derated component values based on temperature, bias voltage and component tolerances when designing filters. In this paper, we demonstrate that field coupling to chokes also results in a derating of its inductance based on the proximity of other metallic parts. Specifically, bulk capacitors and proximity of the housing wall to the choke is considered. Furthermore, we also propose a design guideline for layout engineers regarding component placement on the filter Printed Circuit Board (PCB). If the design guidelines cannot be met due to space constraints, the designer can adjust their component value based on the expected derating value. To illustrate our point, we consider an EMC filter part of a typical DC-DC converter encountered in automotive applications. The filter's performance is then evaluated in the Conducted Emission (CE) test setup as per CISPR25 standards [4].

2. Basic Setup and Filter design.

In the automotive industry, non-linear components are the primary noise sources. The amount of Electromagnetic (EM) noise transmitted to the battery through the PCB and harness is measured using Line Impedance Stabilized Network (LISN), as depicted in Figure 1. Therefore, it is crucial to design a filter that can effectively suppress these emissions. This usually requires quick but thorough analysis and component optimization through spice simulations. However, it is important to note that the EM field coupling between components is often overlooked in spice level simulation, leading to inaccurate results. Our analysis shows degradation of filter performance in the

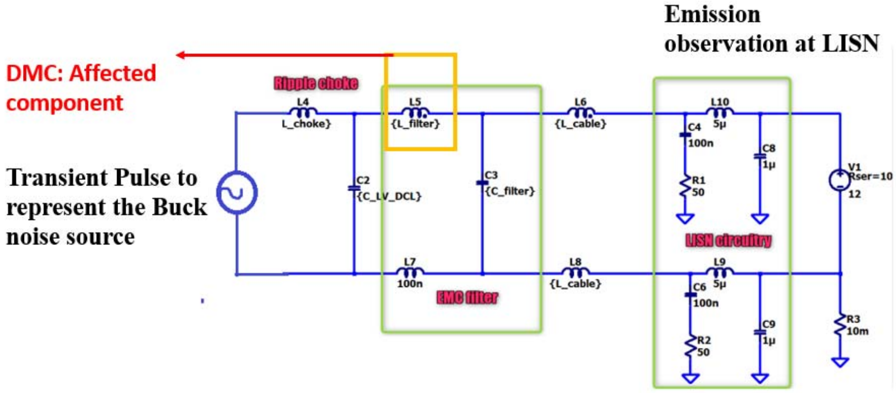

Figure 1. A typical example of a DC-DC converter with EMC filter section on the Low Voltage (LV) side.

presence of conductors near an inductor. To demonstrate this, we have considered a switching voltage signal, a first-order L-C filter, a harness modeled as an inductor, and the network model of the LISN.

In the following section, we delve into the impact of EM coupling on inductance through full-wave EM simulation. This allows us to gain a deeper understanding of how proximity coupling affects the performance of the filter, providing valuable insights for the design and optimization process.

3. 3D modeling of an Inductor.

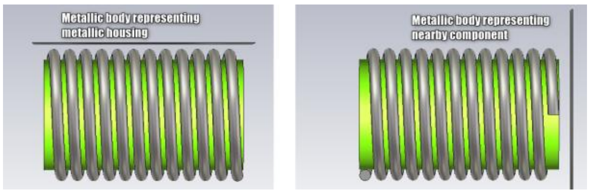

Figure 2. 3D model of the inductor with nearby metal body

An inductor is modeled in full wave EM simulation environment [5] as shown in Figure 2. The impact of proximity coupling from a near-by metallic body on the inductance is studied by varying the distance from the choke.
The metallic body was positioned in two different orientations, as illustrated above. In the first scenario, the metal body intersects the flux generated from the choke. In the second case, the plate runs parallel to the flux. It is evident that the magnetic field is disrupted when a metallic body is perpendicular to the flux. This is visualized by the magnetic (**H**) field distribution along the axial cut plane of the choke in Figure 3.

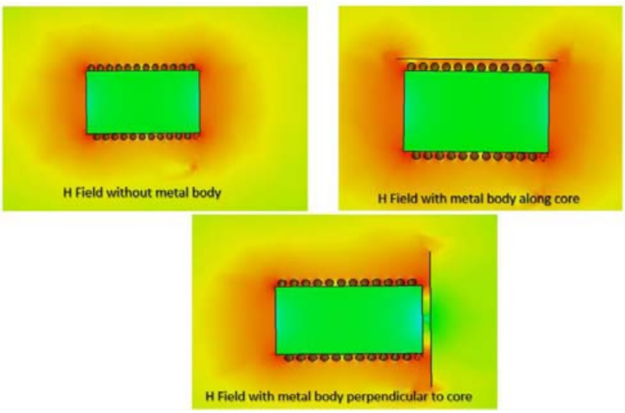

Figure 3. Plot of magnetic field distribution around a choke (a) in free space (b) a conductor placed parallel to the choke axis and (c) conductor placed perpendicular to the choke axis.

4. Results.

The inductance of a choke in free space is simulated. The parameters of the choke are as follows – relative permeability (μ_r) = 1000, coil radius = 0.5mm, core radius = 5 mm, number of turns = 13, pitch = 1.5mm. This arrangement corresponds to an inductance value of 3.8μH. The inductance of the choke is computed by positioning a metallic body at different locations from the choke. It is seen that the inductance reduces as much as 25% when the component or the housing is placed at a distance of half the choke's length as seen in Figure 4. Table 1 lists the variation of the inductance at specific distances from the choke. This effect goes down as the body moves away. It is interesting to note that the effect of a component (choke / capacitor) is much more pronounced than that of a housing. This is primarily due to the obstruction of the magnetic fields from terminating within the choke as seen from Figure 3 (c).
With this knowledge in hand, we utilize the choke as a filtering component and integrate it into a standard CE

Table 1. Variation of inductance for different positions of metallic bodies from a choke

Distance from choke	Metal body perpendicular	Metal body parallel
0.5 mm	2.8 uH	3.55 uH
1 mm	2.95uH	3.6 uH
18 mm	3.7 uH	3.8 uH

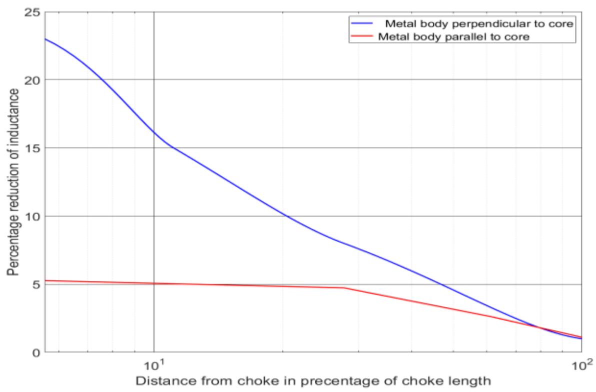

Figure 4. Inductance variation as a percentage for metallic bodies placed at various distances from the choke

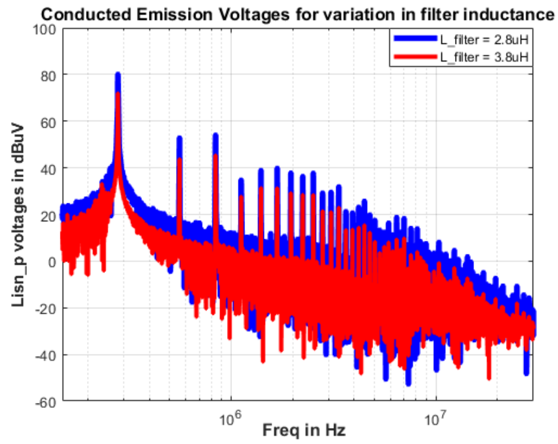

Figure 5. Impact of change of inductance in CE

setup as shown in Figure 5. It can be noticed that emission changes around 4 - 6 dB due to the change in inductance. Based on the filter topology in use the values would change. It is also important to understand that this variation would be critical in deciding the pass/fail criterion of a product.

5. Conclusion

Inductance of the choke being very critical in EMC filter design flow, we need to consider its possible derating due to placement of nearby components or proximity to metallic housing. Placement of other bulk components as well as housing walls relative to the choke needs to be considered during initial filter simulations. We also show that the filter can get derated by as much as 25% depending upon the choke's proximity to other components. A worst case analysis shows that this can result in about 4 – 6 dB change in emissions.

6. References

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