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In-Situ and Contactless Extraction of the Insertion Loss of Switched Mode Power Supply EMC Filter based on Near-Field Scan Measurement

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Résumé/Abstract

1 This work proposes a method to extract the insertion loss, in-situ and in a contactless manner for on board EMI filters that reduce conducted emissions in power converters using Near Field Scanning approach. The proposed approach relies on mutual coupling between NFS probes and on board components at the filter input and output, and by evaluating the transfer function between these points the Insertion loss extraction methodology of both passive and Hybrid EMI filters on board power converter module is presented. This approach can aid the designers to evaluate the performance of the EMI filter in real operation environments in a non-invasive manner.

Ce travail propose une méthode d'extraction de la perte d'insertion, in situ et sans contact, pour les filtres EMI embarqués qui réduisent les émissions conduites dans les convertisseurs de puissance en utilisant l'approche Near Field Scanning. L'approche proposée repose sur le couplage mutuel entre les sondes NFS et les composants embarqués à l'entrée et à la sortie du filtre, et en évaluant la fonction de transfert entre ces points, la méthodologie d'extraction de la perte d'insertion des filtres EMI passifs et hybrides embarqués sur le module convertisseur de puissance est présentée. Cette approche peut aider les concepteurs à évaluer les performances du filtre EMI dans des environnements de fonctionnement réels de manière non invasive.

2 Context

Electromagnetic interference (EMI) from power converters in high power drive systems, in automotive and aerospace applications, challenges reliability and compliance with standards. Traditional bulky passive filters are insufficient for light and compact designs, and hence the need for the adoption of hybrid EMI solutions combining passive and active components. These filters effectively suppress noise, offering superior performance in smaller footprints [1]. Projects like RePOWERDRIVE at IRT Saint Exupéry are advancing multifunctional, compact hybrid filters for power converters using innovative materials and active-passive synergies to deal with industrial constraints. However, the integration of active filters into PCBs complicates performance evaluation, particularly for extracting insertion loss. Current EMI filter evaluation methods, such as MIL-STD-220 and CISPR 17, use standalone filters with fixed load and source impedances ($50\Omega/50\Omega$ or worst-case analysis), which do not account for the effects of PCB layouts and system interactions in embedded designs. Measurements based on this setup don't reflect the real insertion loss, as actual supply and converter impedances differ in the filter's real operating environment. This creates a need for in-situ measurement techniques that accurately assess filter performance in real operating environments, ensuring precise EMI suppression. Near-field scanning (NFS) is a powerful tool for diagnosing PCB-level emission sources during prototyping, eliminating the need for costly EMC facilities [2,3]. The proposed method uses NFS probes to directly evaluate EMI filters performance on board, by injecting (or sensing) an external signal at the filter's input without altering its setup and by measuring the filter's output, the filter's insertion loss will be extracted. This non-invasive approach overcomes above-mentioned limitations, providing board designers with an accurate way of assessing the filter's performance in real operating environment, considering PCB parasitics and interactions.

2. Principles of the proposed approach

The authors in [2] presented a method based on near-field scanning (NFS) to assess the efficiency of decoupling capacitors on power integrity. The proposed method uses a similar technique, involving the coupling of a small magnetic or Electric near-field probe with a component, like a capacitor or inductor, placed on the converter's power supply side (EMI filter input) as shown in the Injection box in Fig 1 (a). As illustrated in [3], a differential-mode (DM) source is created by coupling the probe and an input capacitor placed between the two input cables on the supply side of the converter. In the reception box that is placed upstream at the EMI filter output, Fig 1 (a), a LISN is connected to capture DM and CM, as used in a standard test for automotive applications. The filter components are then modelled as 2- port network, fig 1(b), and by evaluating the S-parameters between the injection box and reception box using a vector network analyzer (VNA) on either powered or

unpowered converter, this method offers an in-situ and contactless method to determine the insertion loss of an EMC filter installed in the power converter.

2.1 Optimization of Mutual coupling

It is essential to obtain the accurate mutual coupling M , as it defines the interaction strength between the probe and the coupled component hence it is crucial for creating the equivalent circuit, fig 1(b). The mutual coupling between the injection probe and the component can be extracted by prior calibration. From Equation 1, if the probe and the component connection trace remain electrically short, Z_{21}^c , which is the transfer impedance, is directly proportional to M [3]. An equivalent circuit can then be deduced, either an equivalent voltage source in series or a current source in parallel for H and E field coupling probes respectively. Great emphasis will be put on the mutual inductance, which depends on the equivalent component coupling surface of the component [4], probe position, probe coupling with other components and analyzing the field emitted by the component (reception box) (i.e. if the field behaves as that of a dipole, it decreases rapidly with distance, typically as $\frac{1}{r^3}$).

$$Z_{12}^c = jM\omega \quad (1)$$

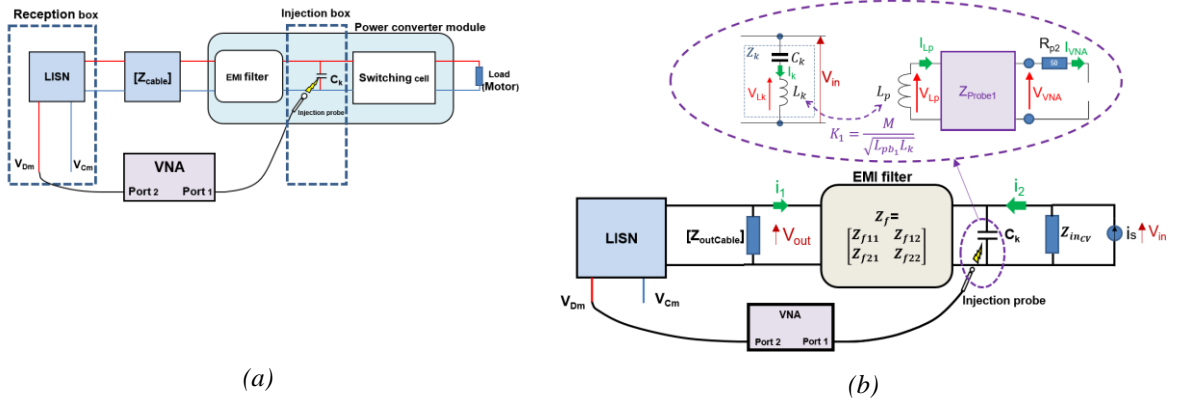


Figure 1: (a) Proposed NFS based method to evaluate the insertion loss of on board EMI filter and the equivalent circuit, (b) Equivalent coupling circuit

2.2 Insertion loss Extraction

By conversion from the S- parameters from the VNA to the Z-parameters, the insertion loss of the EMI filter can be expressed as provided in Equation 2. This is with the assumption that the LISN termination is used and that the probe is coupled on to an input capacitor. The impact of all components installed between coupled capacitor C_k and the $Z_{outCable}$ is represented by a two-port impedance matrix ($[Z_f]$) and treated as an EMC filter.

$$IL(dB) = \frac{V_{outNoFilter}}{V_{outFilter}} = \frac{(Z_{inCV} + Z_{f22})(Z_{outCable} + Z_{f11}) - Z_{f12} \cdot Z_{f21}}{Z_{f12}(Z_{outCable} + Z_{inCV})} \quad (2)$$

where $Z_f = \begin{bmatrix} Z_{f11} & Z_{f12} \\ Z_{f21} & Z_{f22} \end{bmatrix}$ = Two-port impedance matrix representing the EMI filter

Z_{inCV} = Impedance of the converter

$Z_{outCable}$ = Impedance of the cable connecting filter and the LISN

$$Z_{inCable} = Z_{11f} - \frac{Z_{12f} \cdot Z_{21f}}{Z_{inCV} + Z_{22f}}$$

As a secondary advantage of this approach, the mode conversion can be extracted. By exciting a single mode, DM-to-CM conversion or vice versa induced due to filter components asymmetry can be obtained using mixed-mode S-parameters [3].

3 Conclusion

This work proposes a method to extract the Insertion Loss of EMI filter on board power converters in a contactless manner and in-situ. Firstly, we intend to focus on optimizing the mutual coupling between the NFS probe and the component. The LISN is used in the reception box because it is easy to connect and to replicate the standard test

for automotive. The methodology will be extended to aeronautics applications where another means to capture the information on the Reception box will be needed. As such, the LISN will be replaced with a reception probe i.e. (current, voltage, impedance, Near-field or differential Probe). The IL of passive EMI filters will be extracted first and later the hybrid filters will be considered. This methodology therefore provides a means to aid the designers to evaluate the performance of the EMI filters in-situ in a contactless manner hence it is non-invasive, the filter is evaluated in the real operation environment.

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