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Electromagnetic Modeling and EMI Mitigation Techniques for EMC Analysis and Design Optimization in DC-DC Power Converters

By

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Abstract

Electromagnetic compatibility (EMC) has become a critical design consideration in modern electronic systems. As devices increase in complexity and operate at progressively higher frequencies, ensuring correct system operation within a given electromagnetic (EM) environment is essential to guarantee reliability and compliance with regulatory standards. Failure to meet EMC requirements may result in malfunctioning circuits, degraded signal integrity, and unpredictable system behavior.

DC–DC converters, widely used in power electronics for efficient voltage regulation, represent a particularly challenging case from an EMC perspective. Their high switching frequencies and steep transient currents inherently generate both conducted and radiated emissions. Conducted emissions propagate through power distribution networks, potentially affecting adjacent circuitry and compromising reliable operation. Radiated emissions, instead, may induce unintended coupling phenomena, interfering with nearby electronic systems. For these reasons, effective mitigation strategies are required from the earliest stages of the design process.

A widely adopted solution consists in the implementation of electromagnetic interference (EMI) filters. When properly designed and combined with optimized layout and packaging techniques, these filters enable compliance with EMC standards, reduce undesired EM coupling between subsystems and limit the impact of interference on the system's own operation. During the design process particular attention must be devoted to the interaction between the filter and the converter, since it can significantly influence system stability and dynamic response.

In this context, EM simulation tools play a fundamental role. Their adoption is essential for the accurate characterization of parasitic effects and EM interactions, which cannot be adequately captured using conventional circuit-level models.

In light of the considerations discussed above, this dissertation addresses the analysis, mitigation, and characterization of electromagnetic phenomena, particularly in DC–DC converters. EM disturbances are first examined through the identification of the primary mechanisms responsible for their generation and the investigation of how these phenomena affect overall system behavior and influence compliance with EMC requirements.

Subsequently, the state of the art in passive EMI filtering techniques is presented, with a focus on their design and optimization in DC–DC converters operating under Quasi-Square-Wave Zero-Voltage-Switching (QSW-ZVS) conditions, addressing the associated design trade-offs and damping strategies required to ensure effective EMI attenuation while preserving converter performance and proper operating conditions.

The work then provides an overview of the main commercial EM simulation tools, highlighting their capabilities, solution methods, and supported types of analysis. Afterward, particular emphasis is placed on the integration of EM simulation results into time-domain circuit simulations, enabling parasitic effects and EM interactions to be investigated under realistic operating conditions.

Finally, the use of EM simulators for the analysis of electromagnetic fields is discussed, with a focus on near-field magnetic emissions. The corresponding measurement techniques based on magnetic microprobes are discussed, together with the extraction and post-processing of simulation results to enable a direct comparison with the experimental measurements.