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EMI CHARACTERIZATION OF A SYNCHRONOUS DC-DC CONVERTER FOR AUTOMOTIVE FUEL PUMP APPLICATION USING DIFFERENT POWER SWITCHES

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ABSTRACT

The integration of power electronic converters in automotive systems has led to increased challenges in managing Electromagnetic Interference (EMI), particularly in components such as fuel pump drive systems. This paper presents an experimental characterization of conducted EMI-both common-mode (CM) and differential-mode (DM), generated by a synchronous DC-DC converter used to supply a 12V DC motor in a vehicle fuel pump. Two types of power switches, MOSFET and IGBT, are analyzed under identical operating conditions to evaluate their influence on EMI performance. The study is conducted using a dedicated experimental test bench that allows for accurate measurement of EMI emissions in real-world conditions. Results reveal distinct EMI profiles depending on the switching device employed, with the MOSFET configuration showing higher DM noise due to faster switching dynamics, while the IGBT offers a more moderate EMI spectrum. This experimental investigation highlights the importance of switch selection in automotive power electronics and contributes to the design of more EMC-compliant and reliable converter systems for fuel pump applications and beyond.

Keywords: electromagnetic interference (EMI), electromagnetic compatibility (EMC), DC-DC converter, synchronous switching, common-mode and differential-mode disturbances, automotive power electronics.

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1. INTRODUCTION

The rapid evolution of power electronics [1] has transformed the way electrical energy is processed, controlled, and distributed in modern systems. Recent works, such as those by Fang *et al*. [2] and Ishibashi *et al*. [3], emphasize the importance of Electromagnetic Compatibility (EMC) design practices in High-Frequency (HF) power electronics, particularly as systems become more compact and complex. Recent studies, such as those by Kircher [4] and Tatar [5], have further emphasized the importance of EMC considerations in emerging converter topologies, highlighting the trade-offs between performance and Electromagnetic Interference (EMI) behaviour. In particular, the increasing demand for compact, high-efficiency converters [6] has led to their widespread integration in industrial automation [7] [8], electric mobility, aerospace, and renewable energy applications [9] [10]. Static power converters-such as DC-DC choppers [11] [12], inverters, and regulated power supplies-play a central role in enabling the regulation of voltage [13], current, frequency [14], and power flow across a wide spectrum of applications [15] [16]. Their versatility and effectiveness, however, come at the cost of increased EMI, particularly in the HF range.

EMI in power electronics [17] [18] [19] arises primarily due to the fast switching operations of semiconductor devices such as IGBTs, MOSFETs, and SiC transistors [20]. These devices, while enabling precise control and high efficiency [21], also generate transient voltages and currents that couple into surrounding circuits, cables, and the electromagnetic environment [22]. Such disturbances can propagate through conduction or radiation, potentially leading to malfunction or degradation of nearby electronic equipment [23] [24] [25]. To mitigate these effects and ensure safe and reliable operation, compliance with EMC standards is essential [26] [27] [28]. This need has been further underscored by recent studies demonstrating the limitations of purely simulation-based approaches and highlighting the value of experimental methods in capturing real-world EMI phenomena [29] [30]. Experimental analyses, including work by Salhi et al. and Miloudi *et al*. [31], underline the limitations of simulation-based predictions [32] and the necessity of empirical data in real-world applications [33].

Conducted EMI-comprising both Common-Mode (CM) and Differential-Mode (DM) components-remains a significant concern in DC-DC converter applications [34], especially when such converters are embedded in electrically dense environments like automotive systems or renewable energy modules [35]. Previous research has revealed that EMI propagation is influenced by numerous factors, including switching frequency [36], circuit layout [37], parasitic elements [38], and the electromagnetic behavior of inductive and capacitive components [39] [40] [41]. Experimental characterization of HF isolating transformers, for instance, has demonstrated their critical

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impact on EMI under fast-switching conditions, highlighting the need for precise design and integration [42].

In the context of rotating electrical machines [43], especially induction motors [44] and synchronous motors [45], studies have shown that EMI emissions can be reduced by implementing optimized filter designs, appropriate grounding techniques, and shielding strategies [46] [47]. Additionally, toroidal inductors and shielding enclosures have proven effective in minimizing magnetic emissions, thereby reducing CM noise levels in sensitive circuits [48]. The development of HF models and transfer function-based impedance characterization methods has further contributed to our understanding of EMI behavior in complex electromechanical systems [49] [50]. These modeling tools enable better design of EMC filters and provide predictive insight into disturbance behavior over a broad frequency range-from a few Hz to several hundred MHz. Recent investigations have also highlighted the strong influence of motor topology [51], load conditions [52], and switching device types on EMI emission patterns [53]. Notably, experimental comparisons between MOSFETs and IGBTs have demonstrated significant differences in their switching transients, which directly affect CM and DM interference levels [28] [29]. The design of converter topologies, including buck, boost, flyback, and synchronous choppers, further modulates the spectral content and amplitude of EMI emissions, calling for tailored mitigation strategies depending on the application and environment [30].

This body of knowledge is especially relevant in applications such as Hybrid Photovoltaic (PV) systems and electric vehicles, where DC-DC converters are used to regulate and condition power from variable sources and loads [7] [8]. In these systems, HF EMI can compromise both energy efficiency and control accuracy, making EMI mitigation a vital design objective. Moreover, in aerospace and aircraft systems, where weight, space, and reliability constraints are stringent, EMC compliance becomes a critical requirement for system certification and operational safety [31] [32]. Despite extensive progress in simulation-based modeling and analytical prediction of EMI, experimental validation remains indispensable. Laboratory characterization of conducted disturbances allows for the detection of real-world effects such as parasitic interactions, PCB layout influences, and switching noise coupling that are difficult to fully capture in simulations. Accordingly, recent studies have emphasized the value of combining time-domain and frequency-domain measurement techniques to obtain comprehensive EMI profiles and to validate filtering and shielding solutions under actual load conditions [54] [55].
Static converters such as choppers and inverters are increasingly used in the control of DC motors, which require precise modulation of voltage and current to achieve targeted speed and torque profiles. In automotive applications, for instance, synchronous DC-DC converters are widely employed in systems such as fuel pumps, electronic control units (ECUs), and battery management systems. The selection of the appropriate power switching device (e.g., IGBT vs. MOSFET) plays a crucial role not only in energy efficiency and thermal performance but also in the spectral distribution and amplitude of EMI emissions [35] [36].

In this context, the present study aims to advance the state of the art by conducting a detailed experimental evaluation of conducted EMI generated by a synchronous series DC-DC converter powering a 12V DC motor, such as that used in a vehicle fuel pump. Specifically, we investigate and compare the EMI behavior of two power switch configurations: one using an IGBT and the other a MOSFET. The study focuses on both CM and DM emissions under realistic operating conditions. Unlike previous research limited to simulations or partial testing, this work provides a full experimental characterization using a dedicated EMC measurement bench, thereby offering practical insights for engineers and designers in the field.

The main objectives of this research are threefold: (1) to characterize the EMI emissions of a synchronous switching chopper in terms of CM and DM components; (2) to analyze the comparative EMI performance of MOSFET and IGBT switches in this application; and (3) to contribute experimental data and analysis that can guide future EMC-conscious converter designs. Our results aim to inform the design of low-noise, high-performance DC-DC converters for deployment in sensitive environments such as automotive electronics and renewable energy systems.

This paper is structured as follows: Section 2 presents an overview of the converter topology and the power switches used. Section 3 describes the experimental setup and the methodology used for EMI measurement. Section 4 discusses the measured results and provides a comparative analysis. Finally, Section 5 concludes with key findings and future research directions.

2. SERIES CHOPPER AND SYNCHRONOUS SWITCHING CHOPPER

A step-down chopper (Figure-1), also known as a buck converter, is a fundamental electronic device in power electronics used to reduce the average output voltage compared to the input voltage. This configuration incorporates a controlled switch-typically a bipolar transistor, MOSFET, IGBT, or GTO thyristor-placed in series with the load.

Activation of the controlled switch allows current to flow through the load, generating a voltage pulse. By adjusting the duration of switch activation, known as the duty cycle modulation, the average output voltage can be precisely controlled.

To complete the circuit, a freewheeling diode is essential. Positioned in parallel with the load, this diode ensures the controlled switch's smooth deactivation by providing a path for current to circulate when the switch is off. It prevents undesired reverse current flow through the controlled switch. Step-down configurations like these are widely applied in switch-mode power supplies and various industrial applications requiring voltage reduction to meet specific load demands.

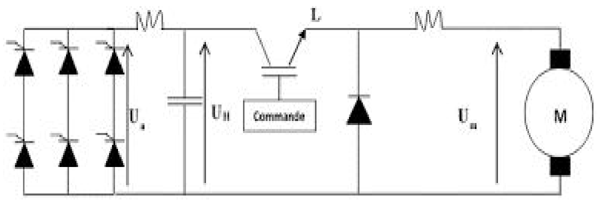

Figure-1. Series chopper.

In the realm of power electronics, the series chopper assumes a critical role in the precise control and management of DC motors. To optimize motor performance, the synchronous commutation chopper is employed (Figure-2). This electronic circuit is designed to chop or modulate an input DC voltage to achieve a desired output.

What distinguishes the synchronous chopper is its synchronized switching mechanism, where the switching action aligns precisely with the input waveform. This synchronization significantly enhances efficiency and control, positioning the synchronous chopper as a pivotal component in a wide array of applications, including power supplies and motor drives.

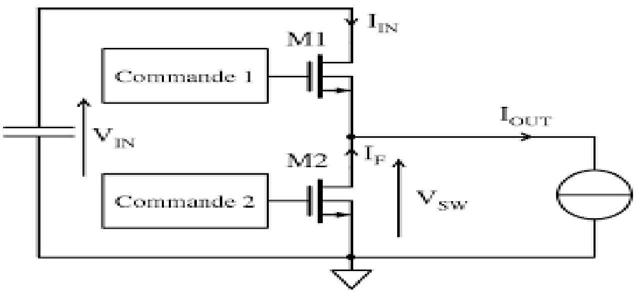

Figure-2. Series chopper.

3. MEASUREMENT OF CONDUCTED EMI

Conducted emissions refer to disruptions in measurable electrical properties that are directly observable at the conductor level, such as voltage and current. These emissions involve undesired High-Frequency (HF) currents circulating within the device and may also manifest as overvoltages at the load's terminals when powered through an extended cable. HF currents typically fall within the range of 150 kHz to 30 MHz, aligning with the bandwidth regulated by prevailing EMC standards. In the context of a single-phase circuit with a power electronic converter as the source of disturbances (as illustrated in Figure-4), these currents can be decomposed into two distinct components.

The LISN (Line Impedance Stabilization Network) serves as a critical filter placed between the power supply network and the input of the tested equipment, fulfilling several essential functions. It effectively isolates the tested equipment from the power supply network, maintains specified impedance levels at measurement points, and directs disturbances towards the measurement receiver.

Conducted disturbances often manifest as HF currents circulating within the device. These currents can be categorized into two distinct modes. The first is the DM current (I_{DM}) (Figure-3), which flows along the standard current path between the power source and the load, traversing the power conductors. While this mode represents typical power transfer, the presence of HF components is undesirable. In contrast, the CM current (I_{CM}) refers to the current flowing through the ground wire. This path, which typically does not contribute to power transfer, can carry HF components, often due to capacitive coupling. Regardless of their coupling mode, these HF currents eventually return through the internal impedances of the electrical network. The specific configuration and layout of the network dictate how these currents are measured.

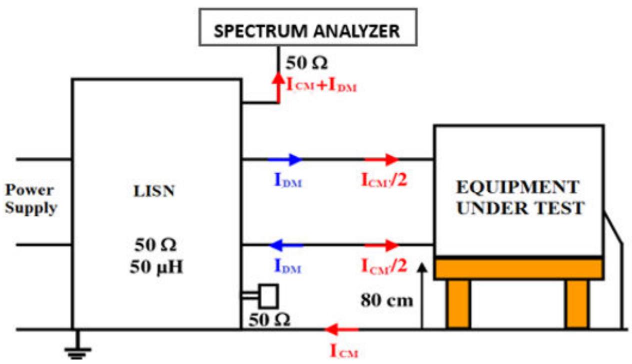

Figure-3. CM and MD test bench.

All electronic power switches act as sources of pollution due to parasitic elements originating from the power supplies themselves. Despite their predominant use in the industrial sector, compliance with EMC standards is essential, particularly with their growing application in the tertiary sector. Companies specializing in power supply design and static converters must address these requirements. Power transistor applications, now commonplace in various service sectors, represent some of the most intricate power structures in terms of design and modeling.

To measure conducted EMI in CM and DM, a series synchronous switching chopper is used with a 12V DC motor drawing 0.98A of current. The converter setup includes two power switches: the IGBT (FGH40N60) and the MOSFET (IRFP4060). An experimental setup, illustrated in Figure-4, has been established to evaluate the conducted EMI. In this setup, the static converter powers a 12W DC motor used in a vehicle's fuel pump, maintaining a constant voltage of 12V.

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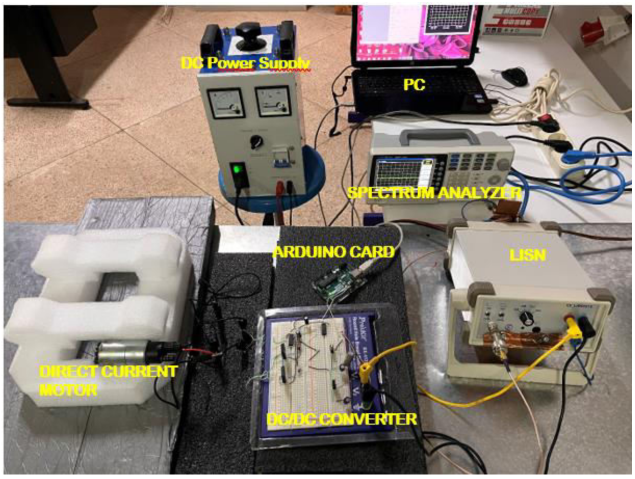

Figure-4. EMC bench for measuring conducted EMI.

4. RESULTS AND DISCUSSIONS

Figure-5 and Figure-6 present the conducted EMI measured from the DC-DC static converter. Figure-6 corresponds to the EMI signature observed when using the IGBT switch, while Figure-7 illustrates the EMI profile associated with the MOSFET-based configuration.

The analysis shows a distinct EMI peak occurring at the moment of switching, which is primarily attributed to the sudden rise in load demand and the corresponding surge in switching activity. In the case of the IGBT-based chopper (Figure-5), the CM and DM interferences display relatively balanced propagation characteristics, with no dominant mode. In contrast, the MOSFET-based chopper (Figure-6) exhibits a significantly higher level of DM interference compared to CM. This can be attributed to the inherently faster switching speed and higher di/dt performance of the MOSFET device, which intensifies HF transients and increases coupling through parasitic inductances. As a result, the MOSFET introduces more pronounced DM disturbances under the same load conditions.

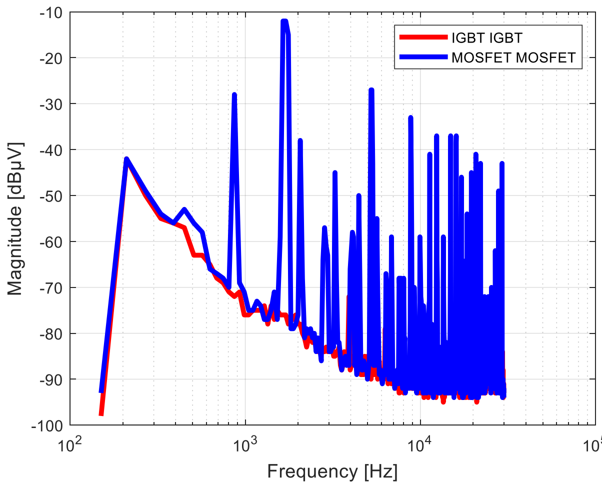

Figure-5. MC and MD for the switch IGBT/ IGBT.

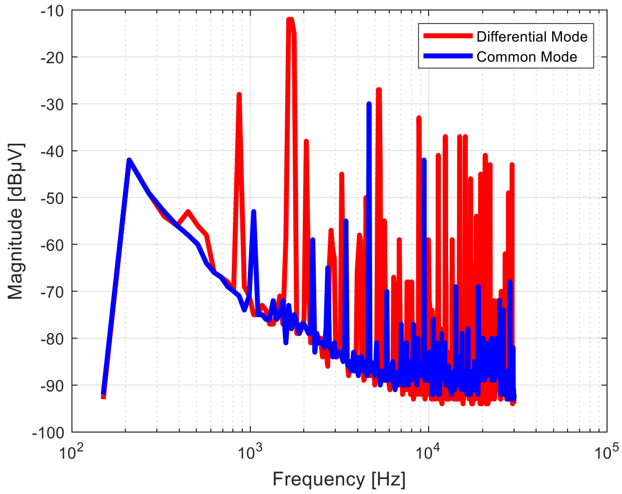

Figure-6. MC and MD for switch MOSFET/ MOSFET.

Figure-7 demonstrates that the CM interferences generated by the MOSFET-based converter are notably higher than those observed with the IGBT configuration. This increase is primarily attributed to the MOSFET's superior switching characteristics. The MOSFET's internal structure-featuring alternating P-type and N-type layers-supports faster switching frequencies and incorporates an intrinsic body-drain diode. This design not only enhances switching efficiency but also contributes to the generation and propagation of CM EMI due to rapid voltage transitions and increased parasitic coupling during switching events.

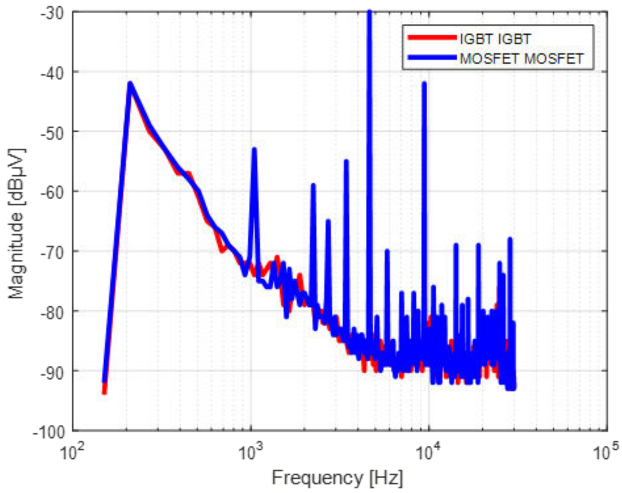

Figure-7. MC for switch IGBT /MOSFET.

In the case of DM interference, as depicted in Figure-8, the disturbances are considerably more pronounced with the MOSFET than with the IGBT. This behavior is largely due to the independent nature of the MOSFET's gate and power circuit operation. As the gate-source voltage (V_{GS}) increases and approaches the threshold voltage ($V_{GS(th)}$), the input capacitance plays a significant role in shaping the transient response. During

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this phase, the MOSFET transitions through a linear operating region, during which the intrinsic body-drain diode remains conductive. This causes the drain current to evolve through the gate path, leading to elevated gate charging currents. The combination of high di/dt and increased input capacitance results in more severe DM EMI generation, underscoring the critical influence of device dynamics on EMI behavior in power converters.

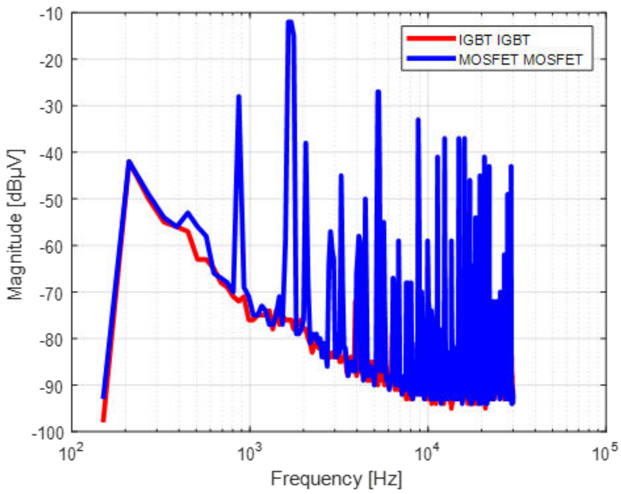

Figure-8. MD for switch IGBT IGBT and MOSFET MOSFET.

When operating the converter with the IGBT as the control switch and the MOSFET as the power switch (Figure-9), distinct EMI peaks are observed throughout the circuit, particularly at the switching frequency of 10 kHz, corresponding to the linear conduction phase. These peaks, which occur precisely at the moments of switch activation, are primarily driven by the substantial inrush current demanded by the load. This behavior highlights the complex dynamic interaction between the two devices: the IGBT's relatively slower turn-on characteristics, combined with the MOSFET's fast response under high-current conditions, introduce transient energy that propagates across the system. Such cooperative operation, while potentially improving efficiency, also results in notable EMI signatures that must be considered in system-level EMC design.

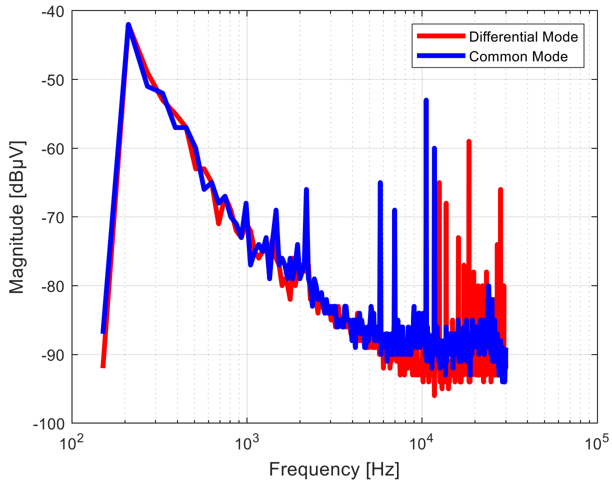

Figure-9. MC and MD for the switch IGBT /MOSFET.

In the second configuration (Figure-10), where the MOSFET serves as the control switch and the IGBT as the power switch, the EMI behavior changes significantly. In this case, HF propagation peaks are more prominent, driven by the MOSFET's inherently faster switching characteristics. The rapid rise in current (di/dt) and voltage (dv/dt) during the switching transitions generates sharp transients that radiate through the power and signal paths. These accelerated switching dynamics amplify the emission of conducted disturbances, resulting in stronger and more frequent peaks across the circuit. This scenario illustrates how the switching device configuration directly influences EMI levels, underscoring the importance of strategic device pairing and gate control in high-performance converter designs.

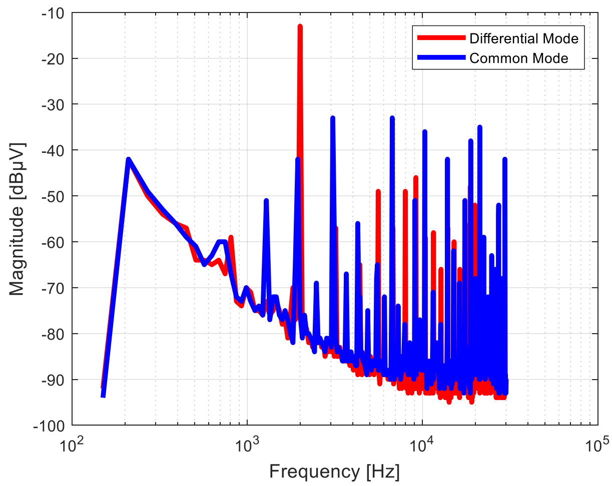

Figure-10. MC and MD for switch MOSFET /IGBT.

5. CONCLUSIONS

This study presented an experimental characterization of conducted electromagnetic interference (EMI) in a synchronous DC-DC converter used to drive a 12V DC motor for automotive fuel pump applications. The analysis focused on comparing the EMI behavior-both common-mode (CM) and differential-mode (DM), of the converter when operated with two different power switching devices: IGBT and MOSFET.

The experimental results demonstrate that the choice of switching device has a significant influence on EMI performance. The MOSFET-based configuration exhibited higher DM interference levels due to its faster switching speed and higher di/dt characteristics. Conversely, the IGBT configuration showed a more balanced EMI profile between CM and DM modes, making it potentially more favorable for applications sensitive to differential-mode noise.

Furthermore, hybrid switching configurations revealed complex interactions between devices, particularly during high-current transitions. When combining an IGBT control switch with a MOSFET power switch, sharp EMI peaks emerged at the switching frequency, driven by the load demand. Reversing this configuration-using the MOSFET as the control switch-amplified high-frequency noise due to rapid voltage and current transitions.

These findings underscore the importance of strategic component selection and configuration in the design of low-noise, EMC-compliant power converters. By providing experimental insights into the EMI characteristics of common switching devices, this work supports the development of more reliable and efficient power electronic systems for automotive and industrial applications.

Future research will focus on integrating filtering and shielding techniques to further mitigate EMI and explore the behavior of wide-bandgap semiconductors such as SiC and GaN in similar converter architectures.

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