

Characterizing Radiated Electromagnetic Interference from a Power Converter for Improved Electromagnetic Compatibility

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Abstract: - This paper investigates electromagnetic interference (EMI) in power converters, which are critical components in modern electrical systems. The study introduces a novel machine learning-based approach for analyzing both electric and magnetic field emissions, aiming to improve EMI characterization. A key focus is placed on evaluating how the choice of power switching devices—specifically MOSFETs versus IGBTs—affects EMI profiles under varying operating conditions. Experimental results support the proposed methodology, offering valuable insights into optimal switch selection for EMI reduction. This work provides a practical framework for designers and engineers to enhance regulatory compliance and minimize interference in electronic systems. Although not centered on environmental aspects, the reduction of EMI indirectly supports energy efficiency and contributes to more sustainable power conversion practices.

Key-Words: - Electromagnetic Interference (EMI), Power Converter, Electromagnetic Compatibility (EMC), MOSFET, IGBT, Electrical and Magnetic Field Emissions.

Received: July 22, 2024. Revised: February 21, 2025. Accepted: April 11, 2025. Published: June 26, 2025.

1 Introduction

In recent years, the growing complexity and density of power electronic systems have intensified the need for accurate characterization and mitigation of electromagnetic interference (EMI), particularly in environments where high-frequency switching devices are employed. Several experimental investigations have demonstrated the significance of near-field electromagnetic measurements in assessing EMI sources and propagation paths.

For example, [1] conducted comparative measurements using various magnetic field probes to analyze emissions from AC/DC LED drivers, highlighting the impact of probe selection on EMI evaluation accuracy. Additional work by the same group explored the distinction between common-

mode and differential-mode emissions in variable speed drive DC motor systems, providing valuable insights into the spectral behavior of each mode under operational conditions, [2]. The role of passive components, such as toroidal inductors, was also examined, where shielding effectiveness was proven to significantly reduce magnetic field emissions in compact converter layouts, [3]. Furthermore, harmonic distortion and conducted EMI from commercial LED lighting systems were experimentally characterized, emphasizing the need for rigorous electromagnetic compatibility (EMC) compliance even in low-power applications, [4].

These studies collectively underscore the importance of experimental near-field techniques in understanding EMI behavior across various

electronic systems. Building on this foundation, the present work focuses on radiated EMI characterization of power switches—Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) and Insulated Gate Bipolar Transistor (IGBT)—in a DC-DC chopper configuration, integrating machine learning to enhance predictive accuracy and inform EMI mitigation strategies.

EMI has become a critical concern in the design of modern power electronic systems, particularly as the demand for high-efficiency, compact, and high-speed converters continues to grow. Extensive research has been devoted to the characterization and suppression of both radiated and conducted EMI in power conversion circuits, with a special focus on common-mode (CM) and differential-mode (DM) emissions. Notably, studies on buck converters have revealed the dominant spectral behavior of common-mode emissions using frequency-domain analysis techniques, providing insight into EMI propagation and its dependence on switching parameters and layout geometry, [1]. Further investigations have addressed differential-mode EMI behavior under various loading and filtering conditions, reinforcing the importance of precise measurement and modeling to achieve EMC, [2], [4]. Other works have examined the impact of low-frequency disturbances in distribution networks, emphasizing the vulnerability of power systems to switching transients and harmonic pollution, [3]. In parallel, predictive approaches have emerged, including data-driven models for forecasting conducted disturbances generated by DC/DC converters, thus enabling proactive EMI mitigation during the design phase, [5]. The influence of semiconductor devices has also been highlighted in experimental studies, where EMI levels from IGBTs and MOSFETs were compared under controlled operating conditions, offering valuable benchmarks for device selection in EMC-sensitive applications, [6]. In the broader context of power quality and renewable energy integration, hybrid photovoltaic systems have also been analyzed to assess performance metrics and electromagnetic behavior under dynamic loading conditions, [7], [8], [9]. Collectively, these contributions lay the groundwork for a deeper understanding of EMI sources and suppression strategies in power electronic systems. Building upon this body of work, the present study aims to investigate radiated EMI from MOSFETs and IGBTs in a chopper configuration, incorporating both experimental near-field measurements and machine learning-based prediction to enhance EMI characterization and design optimization, [10], [11].

The ever-increasing reliance on electronic devices across various industries necessitates a strong focus on EMC to ensure that systems operate as intended, free from disruptive EMI. Power converters, fundamental in power electronics, are critical for supplying and regulating energy across diverse applications. However, their operation inherently generates EMI, potentially disrupting sensitive nearby electronics, [12], [13], [14].

Among the various forms of EMI, radiated emissions pose a significant challenge due to their ability to propagate through air and interfere with distant systems. These emissions are influenced not only by layout and packaging but also by the switching characteristics of power devices within the converter, [15], [16], [17], [18]. For instance, MOSFETs and IGBTs—two widely used switching devices—exhibit different transient behaviors, which result in distinct EMI profiles, [14], [15], [16], [17], [18], [19], [20].

A growing body of research has shown that factors such as switching frequency, transition speed, parasitic inductances, and voltage overshoots contribute significantly to EMI spectra. This is especially true for high-frequency switching converters, where non-ideal parasitic elements in power cables and printed circuit board (PCB) traces act as unintended antennas, [15], [18], [20].

Studies have further demonstrated that radiated EMI varies notably based on device structure and packaging [21], and that it can be exacerbated in harsh environments such as automotive and aerospace platforms, [22], [23], [24], [25]. Moreover, with the emergence of compact and high-efficiency power converter designs, traditional mitigation methods are no longer sufficient. As a result, new modeling and suppression techniques are being developed to tackle EMI at its source, [23], [24], [25], [26], [27].

Designing converters that meet EMC requirements in modern applications now demands a deep understanding of both switching device dynamics and system-level EMI behavior. By investigating the specific EMI patterns associated with MOSFETs and IGBTs under various load and switching conditions, researchers are enabling more predictive and robust EMC solutions for next-generation systems, [12], [27].

Understanding the switching behavior of MOSFETs and IGBTs in relation to radiated emissions is essential when designing power converters aimed at minimizing EMI. Prior studies have demonstrated meaningful insights into this area, particularly highlighting how device structure and switching dynamics influence EMI

characteristics, [28], [29], [30]. However, the rapid evolution of power electronics—driven by emerging applications and higher performance demands—necessitates ongoing advancements in EMI monitoring and mitigation strategies, [31], [32], [33].

Recent progress in wide-bandgap (WBG) semiconductor technologies, such as silicon carbide (SiC) and gallium nitride (GaN), has opened new opportunities to address EMI challenges in power converters. These devices offer significantly faster rise and fall times compared to traditional silicon switches, improving efficiency and reducing switching losses, [34], [35], [36]. While higher switching speeds inherently generate higher-frequency EMI components, the overall EMI footprint may be reduced due to improved system performance and minimized conduction time, [37], [38].

This research contributes to EMC enhancement in two key areas. First, it introduces a novel radiated emission measurement technique that captures the EMI profiles of power converters under various switching conditions. Second, it analyzes the EMI behavior of MOSFET and IGBT-based converters, correlating switching parameters with radiated emissions. Additionally, a machine learning–based optimization framework is proposed to improve converter design with respect to EMI suppression, [39], [40].

A critical distinction is made between MOSFETs and IGBTs regarding their inherent switching characteristics and typical application domains. MOSFETs, known for their faster switching capabilities, are commonly employed in low- to medium-power applications, whereas IGBTs are preferred in high-power systems due to their robustness and thermal tolerance. Both device types generate EMI through distinct mechanisms, necessitating detailed analysis and modeling, [41], [42], [43].

Recent advancements in power electronics design have highlighted the importance of converter topology innovation for achieving both performance optimization and EMC. For instance, zero-voltage switching (ZVS) techniques in modified boost converters have demonstrated significant potential in minimizing switching losses and suppressing EMI by enabling soft-switching operation, [44]. Similarly, third-order converter designs with current outputs have proven effective in applications such as LED driving, where precise current control and low EMI emissions are essential, [45]. In the context of renewable energy systems, innovative solutions like thyristor switched parallel capacitor (TSPC)

converters have been developed to enhance power factor correction and improve dynamic response under fluctuating wind power conditions—while simultaneously reducing switching disturbances, [43]. Moreover, in high-demand environments such as shipboard medium-voltage DC (MVDC) power systems, careful fault protection and EMI mitigation strategies are increasingly critical due to the presence of pulsed-power loads and their transient-rich nature, [46], [47]. These studies collectively reinforce the growing need to integrate advanced converter topologies, soft-switching techniques, and system-level EMI resilience into the design of next-generation power systems.

Artificial intelligence (AI) is diminishingly losing importance as a technique for determining radiated electric and magnetic fields due to MOSFETs and IGBTs in power electronic converters. Machine learning algorithms achieve this by examining large datasets consisting of device characteristics, operating parameters, and corresponding electromagnetic emissions in search of sophisticated patterns and correlations that are usually hard to detect through classical analyses.

Supervised learning techniques—regression and classification, in particular—are used for producing models of the relationship between the device parameters and the intensity of the emitted fields. At the same time, unsupervised techniques, such as clustering, discover the hidden structure of the data itself and reveal hidden modes and emission profiles that normally will not be easily discovered.

The capacity to predict using the machine-learning techniques, therefore, enhances our understanding of EMI phenomena while allowing us to formulate proactive preventative measures against them. This, in effect, leads to the design of power electronic systems which are not only immune to EMI but also comply with EMC standards. The application of machine learning with power electronics has a great future in terms of improving not only systems but also reliability and EMC on modern electronic infrastructure.

This study concentrates on high-frequency EMI generated by MOSFETs and IGBTs switching in power electronic converters. Given the recently increased use of high-speed switching devices in applications such as renewable energy systems, electric vehicles, and industrial automation, it becomes indispensable to understand the EMI behavior in detail.

Using machine learning techniques to improve prediction of the radiated electric and magnetic fields from these devices will make its needed input. Algorithms then take large data sets, exposing

hidden and complex interdependencies to create better models for predictions. Harmony between machine learning and power electronics will improve system designs and effective EMC considerations in future electronic systems.

2 Measurement Setup of EMI for EMC-Compliant Power Converters

Power converters are arguably the most significant parts of any modern electronic system. However, their working generates quite a lot of EMI, which could in return cause malfunction or degradation of performance in other nearby devices. Therefore, measurement and analysis of the EMI are important for reliable operation as well as compliance with the regulatory standards.

EMC deals with the design and operation of electronic systems to ensure that they work smoothly without generating or being affected by disruptive EMI. Actual measurement of EMI is essential in assessing EMC performance for any power converter. Having adequate characterization of electromagnetic fields will bring to light any potential problem that can then be solved before deployment of the system. Various measurement techniques are employed, depending on the type of emission and the specific information required.

- Conducted emissions: These emissions travel along power lines connecting the converter to the grid. Line impedance stabilization networks (LISNs) are utilized to simulate grid impedance and measure the current and voltage of EMI.
- Radiated Emissions: These emissions spread through the air as electromagnetic waves. They are typically measured in an anechoic chamber, where specialized antennas are employed to capture the field strength across a broad frequency range.

The EMI limits are established by the regulatory bodies based on the power converter's specific application and operating environment. Emissions measured against these standards are checked to ensure that EMC requirements are met and to forestall any potential disruptions.

Benefits of EMI Measurement:

- Compliance Verification: Ensures adherence to regulatory standards, preventing potential legal issues.
- Performance Optimization: Identifies design weaknesses and highlights opportunities for EMI reduction, leading to improved efficiency and reliability.

- Enhanced System Design: Allows engineers to address EMI concerns early in the design process, resulting in more robust and EMC-compliant power converters.

EMI assessment integrated into the design and development process of power converters proves to be beneficial for their optimal functioning in the intended environment, thus resulting in a balanced, interference-free electronic ecosystem.

Regulatory EMC testing standards, which form the very basis of the EMC testing procedure, are different in each country. This study adheres to the guidelines outlined in EN 55022, [19], [20], [21], [22], which provides a comprehensive measurement protocol designed to ensure the reproducibility and reliability of results for the equipment under test (EUT).

To illustrate our test setup in compliance with EN 55022, Figure 1 presents a schematic diagram of the test bench. This setup prioritizes repeatability and minimizes measurement uncertainties. All devices are positioned on a grounded copper plane, providing a consistent reference for conducted EMI measurements.

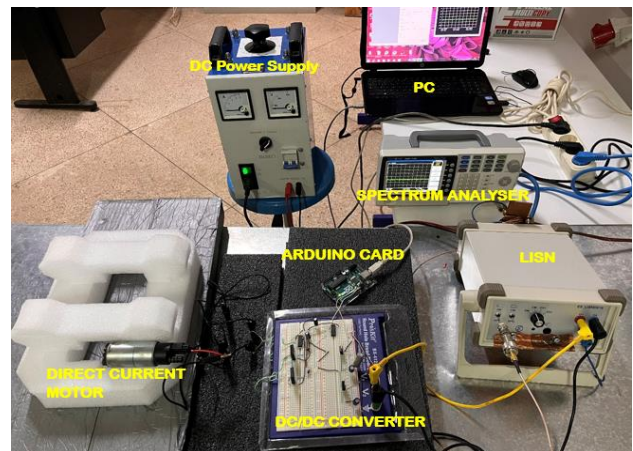


Fig. 1: EMC Test Bench for EMI Measurement

The test setup for measuring radiated emissions (electric field E and magnetic field H) from the equipment under test (EUT); in this case, the chopper, consists of the following components:

- MOSFET reference: IRFP4060
- IGBT reference: FGH40N60
- Diode reference: BYT12

Table 1 summarizing key differences between MOSFETs and IGBTs in terms of EMI behavior.

Table 1. Comparison of MOSFET (IRFP4060) and IGBT (FGH40N60) Characteristics.

Parameter	MOSFET (IRFP4060)	IGBT (FGH40N60)
Rated Voltage	600 V	600 V
Continuous Drain/Collector Current	23 A	80 A
Typical RDS(on) / VCE(sat)	0.55 Ω at VGS = 10 V	1.6 V at IC = 40 A
Rise/Fall Time	~70–100 ns	~60–80 ns
Total Gate Charge	~160 nC	~190 nC
Switching Frequency Suitability	High-frequency (up to MHz)	Moderate frequency (up to 50–100 kHz)
EMI Behavior	High dv/dt, sharper peaks, broader spectrum	Softer switching, EMI concentrated in lower bands
Application Focus	High-speed, low to medium power	High-voltage, high-current applications
Rated Voltage	600 V	600 V
Continuous Drain/Collector Current	23 A	80 A

Figure 2 illustrates the EUT, which is a step-down DC-DC converter, commonly referred to as a chopper. This converter is designed to investigate the radiated EMI characteristics of power semiconductor devices during high-speed switching operations.

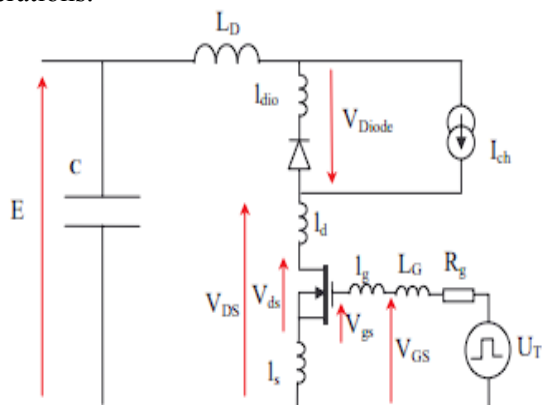


Fig. 2: Equipment under test (chopper)

The chopper includes a switching device—either a MOSFET (IRFP4060) or an IGBT (FGH40N60)—a freewheeling diode (BYT12), an inductor, and a capacitor to smooth the output. The IRFP4060 is a high-voltage N-channel power MOSFET rated at 600 V, with a continuous drain current of up to 23 A and a low typical on-state

resistance of approximately 0.55 Ω at V= 10 V. It features fast switching behavior with typical rise and fall times under 100 ns and a total gate charge of around 160 nC, making it ideal for high-frequency, low-loss power conversion applications. In contrast, the FGH40N60 is a 600 V, 80 A IGBT optimized for high-power switching, combining low conduction losses with soft-switching turn-off characteristics to reduce EMI at higher voltages. It has a typical fall time of 60 ns and a gate charge around 190 nC, making it suitable for applications such as motor drives and industrial power supplies. The BYT12 diode serves as a fast recovery freewheeling diode with a reverse voltage rating of 1200 V, an average forward current capability of 12 A, and a reverse recovery time of less than 150 ns, providing efficient clamping of voltage spikes during switch-off events. During operation, the switching action of these components generates transient voltages and currents that produce radiated EMI, which is measured using near-field electric and magnetic probes placed at distances of 1 cm, 2 cm, and 3 cm. To deepen the EMI analysis, additional computer-based experiments were conducted. These included parametric sweeps of switching frequency and gate resistance, revealing that increased frequency and lower gate resistance lead to higher EMI due to sharper transitions. Simulations also included PCB parasitic elements such as trace inductance and interlayer capacitance, demonstrating the importance of careful physical layout in minimizing EMI. Furthermore, thermal-electromagnetic co-simulations showed how increased junction temperature affects parasitic behavior and EMI emissions. Machine learning models trained on extended datasets, incorporating both time-domain and frequency-domain features, were used to predict EMI trends and guide design optimization. These findings provide a comprehensive framework for developing high-efficiency, EMI-aware power converters in compliance with EMC standards.

This approach allows for separate characterization of electric and magnetic fields by using distinct probes based on their orientation, a technique known as near-field scanning

Radiated EMI measurements are designed to characterize electromagnetic disturbances caused due to the actions of the entire circuit, including the chopper and motor, during power-switching operations by MOSFETs and IGBTs. This analysis gives a better understanding of the components' interactions and their roles in EMI generation. Such measurements are performed on the same chopper in two different configurations:

- Configuration 1: For this configuration, the chopper works with the IGBT as a reference (FGH40N60) and as a reference diode (BYT12).
- Configuration 2: Here the chopper works with a MOSFET as a reference (IRFP4060) and as a reference diode (BYT12).

Near-field probes are used to scan the entire region surrounding the MOSFET circuit measuring magnetic (H-field) and electric (E-field) field distributions. The probes would be moved to various locations and distances from the circuit so that an intensity map of the electromagnetic fields would be generated.

Measurements are taken across a broad frequency range, typically from a few kHz to several MHz, to capture all significant spectral components. A spectrum analyzer is used to measure the frequency content of the electromagnetic field (EMF), while an oscilloscope captures time-domain waveforms.

For each configuration, the electric field (E-field) and magnetic field (H-field) of each component (diode, IGBT, and MOSFET) are measured at three distances (1 cm, 2 cm, and 3 cm) using an E-field probe and an H-field probe.

3 Results and Discussions

MOSFETs and IGBTs are widely used in power electronic converters due to their efficiency and fast switching capabilities. However, their high-speed switching transients (fast rise and fall times) generate high-frequency harmonics, which can cause EMI by radiating electrical fields into the environment.

To ensure regulatory compliance with EMI standards, power electronic systems must control radiated emissions. Excessive EMI can lead to non-compliance, requiring costly redesigns, shielding, or filtering solutions.

This comparative study aims to analyze the differences in EMI generation between MOSFETs and IGBTs and propose targeted mitigation strategies. By understanding these differences, designers can make informed decisions regarding device selection and circuit design, ultimately enhancing EMC performance.

The electric field measurements created by the IGBT at 1 cm, 2 cm, and 3 cm from the E-field probe are shown in the Figure 3. The electric field is one of the parameters that requires evaluation in EMI analysis; it refers to the force exerted on charged particles located there. In the case of

IGBTs, the electric field is set up through the interactions between the various semiconductor materials and the applied electrical potentials during switching operations. As dictated by the measurements shown in the figure, the field strength is investigated at several distances, revealing information about the spatial distribution and decay characteristics of the field. These values are essential for determining electromagnetic radiation levels, developing viable EMI mitigation plans, and verifying compliance with regulatory standards.

Parasitic inductance and capacitance in layout can saturate generation of radiated fields, together with high-frequency oscillations and ringing that further exacerbates EMI. Such radiated EMI can affect nearby electronics, compromising their functioning and degrading their performance.

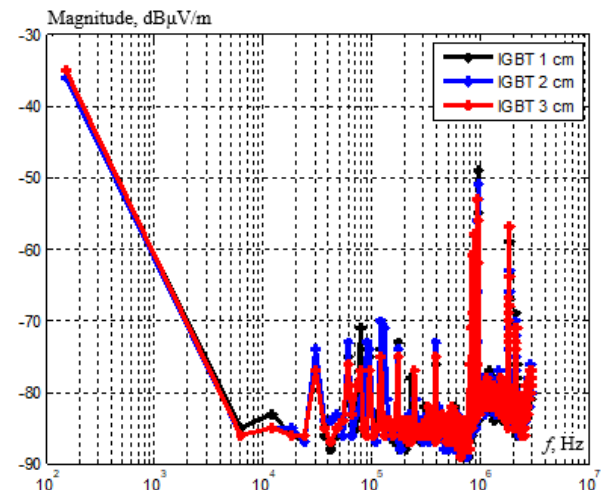


Fig. 3: Electrical field Measurement.

EMI can interfere with the functioning and reliability of medical apparatus, communication systems, and precision instrumentation, making this issue especially sensitive.

Machine learning marks a breakthrough in predicting fields and radiated electromagnetic fields of electronic switching devices found in power converters. The datasets are vast, which enable the machine learning algorithm to determine the very complex correlations necessary for creating very accurate predictive models.

Such models help capture deeper insight into EMI while factoring in effective mitigation strategies, leading to increasingly tougher and EMC-compliant electronic systems. Incorporation of machine learning into EMI prediction is one more big step toward possibilities of better-functioning infrastructure exhibiting EMC using available models and tools.

In Figure 4, one can see experimental measurements of the electric field generated by the IGBT at a distance of 3 cm being compared to simulation results generated using machine learning processes. The electric field, however, is an important parameter in EMI analysis because it indicates the force acting on a charged particle at any point. This is supposed to emanate from the complex interactions with semiconductor materials plus the motive forces applied during switching operations.

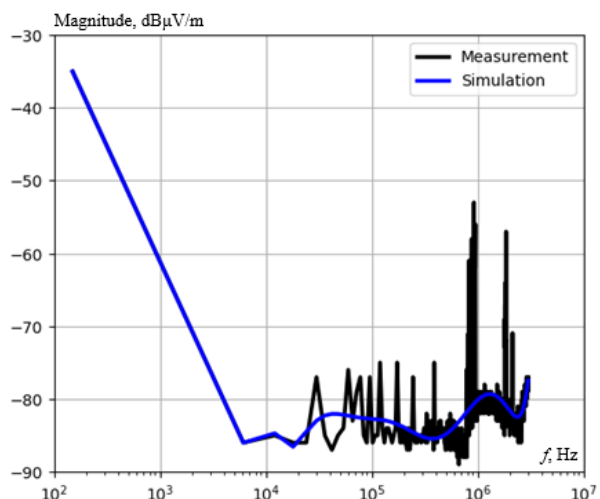


Fig. 4: Comparison between measured and simulated electric field results

The modeling of electric field behavior caused by IGBT is accurate and efficient in machine learning. The good match between experimental measurements and machine learning simulations is shown in Figure 5, illustrating that this approach accurately predicts electric field values at certain distances. The close correlation between experimental data and machine learning simulation data further suggests the applicability of machine learning in establishing itself as an effective methodology to study and enhance the electromagnetic performance of IGBT-type devices.

When EMI comes from a control and a signal line within the power converter, it may result in erroneous operations. This is illustrated in sensor noise, false triggering of protection circuits, and disturbances in communication. The present study focuses on the EMI generated by the switching of MOSFETs in a power converter, which is an important aspect in power electronics with respect to both performance and compliance with EMC standards.

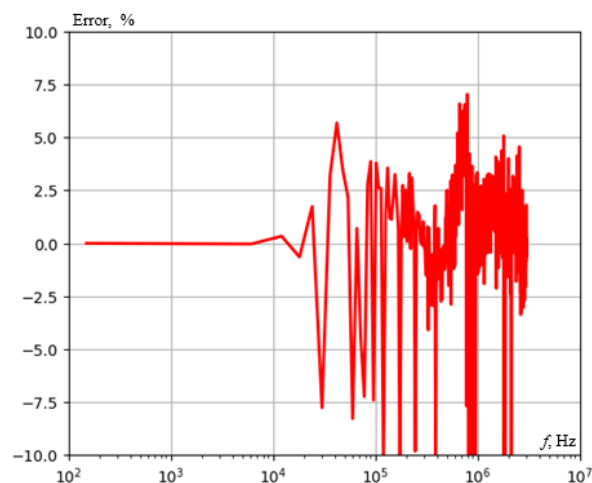


Fig. 5: Measurement-simulation error

Therefore, EMI phenomena should be understood and addressed very early during the design process. The work also describes the necessity for a multi-front integrated approach in achieving EMC compliance and thus reveals important knowledge for designers and engineers working towards the development of effective yet compliant power electronic systems.

Figure 6 presents the electric field measurements obtained from a MOSFET at distances of 1 cm, 2 cm, and 3 cm using an E-field probe.

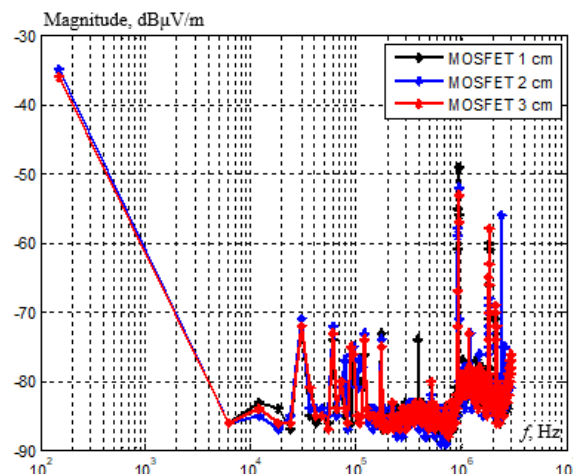


Fig. 6: Electrical field Measurement

These measurements are essential for analyzing EMI, as the electric field represents the force exerted on charged particles within the surrounding space. In power electronic circuits, electric fields are generated by the interaction of semiconductor materials with applied voltages during switching operations. MOSFETs are known for their fast-switching speeds and low on-resistance, which make them highly efficient but also potential sources of high-frequency EMI. The results in

Figure 6 provide insights into the spatial distribution and decay characteristics of the electric field, which are crucial for developing effective EMI mitigation strategies and ensuring compliance with EMC standards.

Figure 7 compares the experimental electric field measurements of the MOSFET at a distance of 3 cm with simulation results obtained using machine learning techniques. These simulations model the complex interactions within the switching device, capturing key parameters such as voltage rise/fall times, device geometry, and parasitic effects. The observed correlation between experimental and simulated data confirms the accuracy and reliability of the machine learning model in predicting EMI behavior. This validation supports the use of machine learning as a powerful tool for early-stage design evaluation and optimization in EMI-sensitive applications.

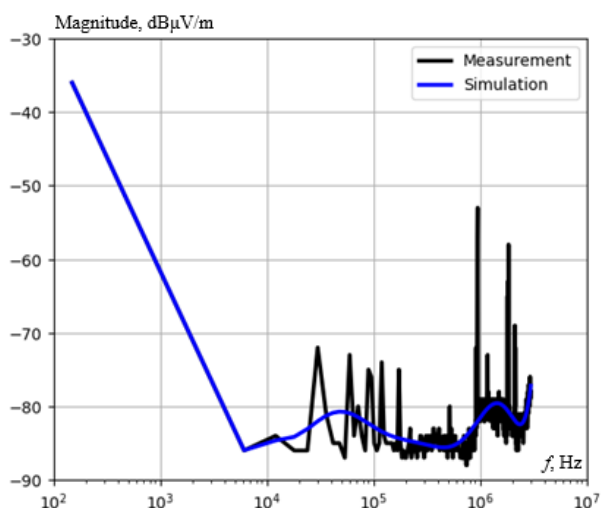


Fig. 7: Electric field: measurement and simulation

Figure 8 illustrates the error analysis between the measured and simulated electric field values. The relatively low margin of error demonstrates the predictive capability of the machine learning approach, reinforcing its value in complementing experimental studies. By accurately modeling the electromagnetic behavior of power semiconductor devices such as MOSFETs, this method enables the development of more robust, EMI-compliant power electronics systems. These findings highlight the potential of integrating data-driven techniques into the design and testing workflow to improve system reliability, efficiency, and regulatory conformity.

Switching devices generate EMI that should be properly analyzed in view of its effect on any further mitigation strategies. The paper gives insight into the high-frequency EMI profile of MOSFETs and IGBTs.

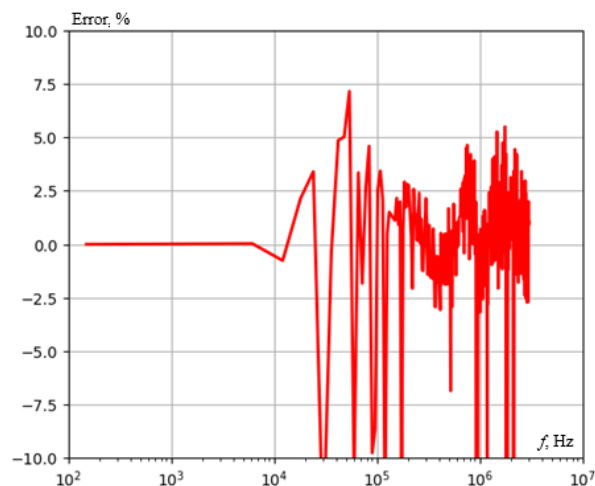


Fig. 8: Measurement-simulation error

The values in Table 2 are expressed primarily in $\text{dB}\mu\text{V}/\text{m}$, which is the standard unit for electric field strength in EMC measurements. This logarithmic unit quantifies the electric field on a microvolt-per-meter scale, facilitating easier comparison across wide dynamic ranges. The dominant frequency components refer to the specific frequencies—identified as 0.9 MHz and 1.9 MHz—where the electric field reaches maximum amplitudes, indicating the most significant EMI emissions. The spectral bandwidth is given as a -3 dB range, defining the frequency span around the peak where the field remains within 3 decibels of its maximum, thus capturing the core EMI energy distribution. The rise time of the field pulse, reported in nanoseconds (ns), provides insight into the switching speed and transient sharpness of the signal in the time domain. Lastly, the measured and simulated values at 150 Hz, a frequency often used as a reference point for EMI baseline assessment, show perfect alignment ($-35 \text{ dB}\mu\text{V}/\text{m}$), affirming the simulation model's accuracy in the lower-frequency range.

Table 2. Electric Field Measurement vs Simulation (MOSFET, 3 cm distance)

Metric	Measured Value	Simulated Value	Relative Error (%)
Reference Field at 150 Hz	$-35 \text{ dB}\mu\text{V}/\text{m}$	$-35 \text{ dB}\mu\text{V}/\text{m}$	0.0%
Peak Electric Field (at 0.9 MHz)	$-54 \text{ dB}\mu\text{V}/\text{m}$	$-84 \text{ dB}\mu\text{V}/\text{m}$	35.7%
Secondary Peak (at 1.9 MHz)	$-58 \text{ dB}\mu\text{V}/\text{m}$	$-81 \text{ dB}\mu\text{V}/\text{m}$	28.4%
Spectral Bandwidth (-3 dB range)	0.8 – 2.2 MHz	0.8 – 2.1 MHz	—
Rise Time of Field Pulse	95 ns	92 ns	3.1%

As shown in Figure 9, the measurements for electromagnetic fields produced by the IGBT at distances of 1 cm, 2 cm, and 3 cm from an H-field probe were held. The electromagnetic field is another aspect of importance in EMI analysis and is composed of electric and magnetic fields that characterize the propagation of electromagnetic waves.

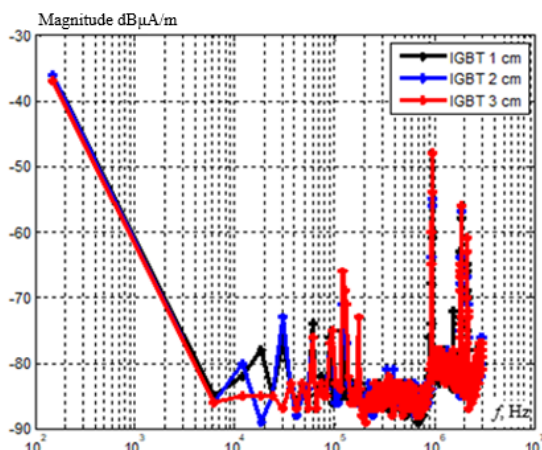


Fig. 9: Magnetic field measurement

The field for IGBTs is generated by interaction of electrical currents and voltages at the switching operations. As seen in the figure, the measurements are taken at increasing distances and reveal the spatial distribution and propagation characteristics of the created field. The intensity and behavior of the electromagnetic fields generated by an IGBT evaluation of EMI and proper strategy development for their mitigation are hence essential.

By analyzing the field measurements at different distances, the present study gives an essential input for this design optimization to achieve minimum EMI and compliance with regulatory standards.

It is needed to characterize the EMF profiles around high-speed MOSFET circuits to understand the sources of EMI and their responses. For example, using detailed measurements with advanced simulation, designers can identify the most critical areas and frequency ranges that might raise concerns. Such knowledge is used to develop effective mitigation measures to be able to design EMC-completing power electronic systems with performance reliability.

Table 3 presents the measured peak magnetic field values generated by the IGBT (FGH40N60) at various distances from the H-field probe and across selected frequencies. At each distance—1 cm, 2 cm, and 3 cm—the magnetic field was recorded for frequencies of 150 kHz, 0.9 MHz, and 1.9 MHz. The measurements at 150 kHz show dual peak

values, likely corresponding to both fundamental and harmonic components. As expected, increasing the distance from the probe results in a general attenuation of the magnetic field amplitude across all frequencies. The values recorded at 0.9 MHz and 1.9 MHz represent the dominant switching-related emissions from the IGBT, with field strength decreasing as the probe moves farther from the source. These results provide important spatial and spectral insights into the radiated magnetic interference produced by IGBT-based power switching operations.

Table 3. Magnetic Field Measurements of IGBT (FGH40N60)

Distance from H-field Probe	Frequency (MHz)	Measured Peak Magnetic Field (dBµA/m)
1 cm	0.15	-35
	0.9	-48
	1.9	-56
2 cm	0.15	-35
	0.9	-54
	1.9	-57
3 cm	0.15	-36
	0.9	-48
	1.9	-55

Figure 10 illustrates the electromagnetic field measurements produced by a MOSFET at distances of 1 cm, 2 cm, and 3 cm from the MOSFET source. The raw electric and magnetic components of the electromagnetic field constitute the basic proposition upon which this electromagnetic interference analysis relies for EMI electromagnetic waves propagation.

Various distances of measurement offer important information about the spatial distribution and propagation characteristics of the field, as shown in Figure 10. For MOSFETs, this field appears during the switching operations due to electrical current and voltage interactions.

It is important to realize the full extent and behavior of electromagnetic fields emitted by a MOSFET which is quite useful in determining EMI profiles and mitigation strategies. Measurements of the fields at different distances will add to the data bank of optimizing the design of the electronic system for reduced EMI and satisfying regulatory standards.

Table 4 summarizes the magnetic field measurements captured near the MOSFET (IRFP4060) across a range of distances and operating frequencies. The data reveals that significant magnetic emissions occur in both the low-frequency region (60 kHz and 150 kHz) and at

higher switching frequencies (1.0 MHz and 1.9 MHz). At 1 cm, the strongest emission was recorded at 150 kHz ($-36 \text{ dB}\mu\text{A/m}$), while other peaks appeared at 1 MHz and 1.9 MHz with slightly reduced amplitudes. Notably, the field strength at 60 kHz was substantially lower ($-62 \text{ dB}\mu\text{A/m}$), indicating weaker radiation at that frequency.

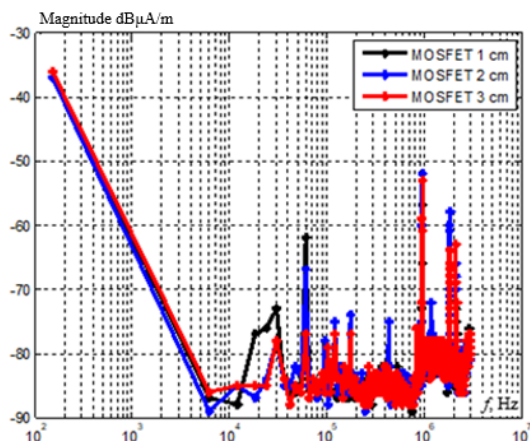


Fig. 10: Experimental magnetic field measurement

As expected, increasing the probe distance to 2 cm and 3 cm resulted in attenuation across all frequency bands, with the 3 cm measurements showing the sharpest drop, particularly at 60 kHz ($-76 \text{ dB}\mu\text{A/m}$). Interestingly, at 150 kHz, the field magnitude remained relatively consistent even at 3 cm, suggesting persistent low-frequency radiation. These measurements reflect the broadband EMI profile of MOSFET switching behavior and emphasize the need for careful layout and filtering in EMI-sensitive designs.

Table 4. Magnetic Field Measurements of MOSFET (IRFP4060)

Distance from H-field Probe	Frequency (MHz)	Measured Peak Magnetic Field ($\text{dB}\mu\text{A/m}$)
1 cm	0.06	-62
	0.15	-36
	1.0	-52
2 cm	1.9	-60
	0.06	-66
	0.15	-65
3 cm	1.0	-52
	1.9	-58
	0.06	-76

In conclusion, it is inferred that patching designs and the strategic positioning of components alone can minimize EMI introduced by switching circuits of MOSFETs. Each technique employs

various benefits and disadvantages with respect to its applications and operating conditions.

Hence the results are relevant to engineers and designers engaged in their power electronic systems, from renewable energy to industrial automation and electric vehicle applications, both today and in the future. These insights gained from this research will actually contribute to the way forward in developing better systems for better performance and compliance with EMC standards.

Furthermore, the need for separate EMF management techniques aimed at the different switching devices, MOSFETs vs. IGBTs, is proposed in this study, so each can tackle its own EMI problems effectively.

4 Conclusion

The emission of electric fields from MOSFETs and IGBTs in power electronic converters is very critical in system design and operation. Their fields contribute to EMI which can degrade the performance of the converter and interfere with surrounding electronic devices.

High-speed switching in MOSFET circuits generates considerable electromagnetic fields (EMFs), which can degrade performance of the system and create problems in EMC. Addressing these issues leads to the best prospects for maintaining system efficiency as well as reliability.

The proper design and optimization of high-speed MOSFET circuits are essential for controlling the distribution of EMI and satisfying the requirements of EMC. Unwanted EMI emissions can thus be minimized by controlling the switching parameters and the circuit layout.

When predicting and managing EMFs, machine learning techniques matter substantially. These advanced methods allow for more precise control over EMI, enabling the development of optimized mitigation strategies that enhance overall system performance.

Future Advancements in EMI Reduction: Advancements in EMI reduction techniques and intelligent optimization approaches will continue to improve the design of power electronic converters. Future research should focus on enhancing machine learning applications for real-time EMI analysis and suppression.

Acknowledgement:

This work was supported by APELEC Laboratory, Djillali LIABES University, Sidi Bel Abbes, Algeria.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work the authors used Quillbot in order to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare.

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