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Experimental electromagnetic compatibility of conducted electromagnetic interferences from an IGBT and a MOSFET in the power supply

Introduction. *Most electromagnetic compatibility studies carried out in the context of power switch research are generally valid for low frequencies. This frequency restriction appears to be too restrictive for a complete analysis of the electromagnetic interference conducted.* ***The novelty*** *of this work lies in the load-dependent an optimal selection of IGBTs and MOSFETs for least-disturbance power switching in the frequency range from 150 kHz to 30 MHz, based on an optimal experimental selection procedure and show the impact of load value on switch switching and noise generation.* ***Purpose.*** *Analysis of the fundamental possibility of selecting a switching device with a power supply based on an experimental measurement which allows to increase the reliability of the entire mechanism operation and significantly simplify the design.* ***Methods.*** *In this paper, the proposed study is used and compared with experimental results at low and high frequencies. Then, a comparison is made for conducted electromagnetic interference (common-mode and differential-mode) generated by IGBT and MOSFET for different loads, and the proposed methodology is verified on an experiment suitable for predicting terminal overvoltage analysis and conducted electromagnetic interference problems.* ***Practical value.*** *The primary method for establishing a conducted electromagnetic interference source for switching devices is based on IGBT and a MOSFET depending on the resistive load.* References 22, figures 17.

Key words: **electromagnetic interference, electromagnetic compatibility, common-mode, differential-mode, IGBT, MOSFET.**

Вступ*. Більшість досліджень електромагнітної сумісності, які проводяться в контексті досліджень силових вимикачів, зазвичай застосовуються для низьких частот. Це обмеження за частотою видається занадто жорстким щодо повного аналізу електромагнітних перешкод.* ***Новизна*** *даної роботи полягає у залежному від навантаження оптимальному виборі IGBT і MOSFET для комутації потужності з найменшими перешкодами в діапазоні частот від 150 кГц до 30 МГц, на основі оптимальної експериментальної процедури вибору і впливу величини навантаження на перемикання перемикачів і генерацію шуму.* ***Мета****. Аналіз принципової можливості вибору комутаційного пристрою з джерелом живлення на основі експериментального виміру дозволяє підвищити надійність роботи всього механізму та суттєво спростити конструкцію.* ***Методи****. У цій статті запропоноване дослідження використовується та порівнюється з експериментальними результатами на низьких та високих частотах. Потім проводиться порівняння кондуктивних електромагнітних перешкод (синфазних та диференціальних), що генеруються IGBT і MOSFET для різних навантажень, і запропонована методологія перевіряється в експерименті, який підходить для прогнозування аналізу перенапруги на клемах і проблем кондуктивних електромагнітних перешкод.* ***Практична цінність****. Основний метод створення кондуктивного джерела електромагнітних перешкод для комутаційних пристроїв ґрунтується на використанні IGBT та MOSFET залежно від резистивного навантаження.* Бібл. 22, рис. 17.

Ключові слова: **електромагнітні перешкоди, електромагнітна сумісність, синфазний режим, диференціальний режим, IGBT, MOSFET.**

Introduction. The proliferation of devices employed in power electronics has witnessed a significant upsurge in recent times. Rooted in the principles of semiconductor switching, these devices have now permeated diverse domains, including land and air transportation, consumer-focused household applications, and even the realm of renewable energies [1, 2].

The functionality of static converters carries an environmental detriment due to their swift switching intervals marked by substantial amplitudes. These rapid switching processes serve to curtail losses during transitions by virtue of the simultaneous presence of voltage and current within the switches. The orders of magnitude for the gradients of these transitions may span from 100 to 1000 A/μs for dI/dt, while dV/dt values range from 5 to 50 kV/μs [3]. Additionally, the markedly high switching frequency stands as an additional contributor to electromagnetic pollution, varying from 100 Hz to 1 MHz.

Electromagnetic compatibility (EMC) has emerged as a critical design requirement for switching power supplies. The required standards ensure that a system can work satisfactorily in its environment without causing unbearable electromagnetic disruptions to neighboring equipment.

Because the main electromagnetic interference (EMI) sources in power electronics are converter switching and essentially produce conducted emissions [4-8] disturbances can be classified into two types based on their modes of propagation:

1) conducted disturbances, which propagate through electrical conduction;

2) radiated disturbances, which circulate through an electromagnetic field [9-11].

A switch-mode power supply must follow the same piping requirements as most modern electrical equipment.

In the field of power electronics, a conversion chain typically consists of multiple stages (Fig. 1).

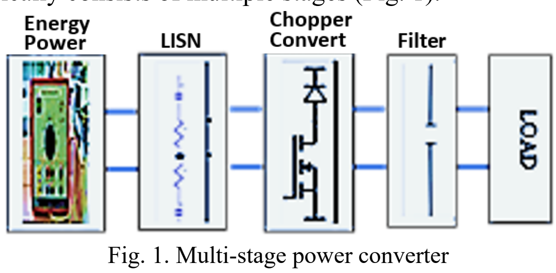

Fig. 1. Multi-stage power converter

These stages often include a rectifier followed by a switching stage, which could be a variable speed drive, a switching power supply, or an inverter for induction heating systems. The assessment of EMC takes place at various levels, including power lines, rectifiers, converters and their control systems, filters, and loads [12-14].

The switching cell and its control energy conversion in power electronics is based on two complementary phases: switching and energy storage. Switching is achieved using power switches with semiconductor components. There are switches with controlled switching (MOSFET, IGBT, JFET) that require control, and others with natural switching (diode, Schottky). Energy storage occurs in passive components like capacitors and inductors. The integration of these two phases is the principle behind the switching cell. The study of power transistors is not a new issue [15-17], and relevant studies have been carried out throughout the evolution of power systems and power conversion technologies. Power transistors are the primary source of EMI and EMC issues in power equipment.

This paper focuses on the EMI-EMC (common-mode (CM) and differential-mode (DM)) design of high-frequency (150 kHz to 30 MHz) power transistors (MOSFET and IGBT) for high-frequency and high-power applications. A background description and review are provided to assist characterize this work and its originality. The experimental method used for identifying high-frequency behavior is presenting oneself in simple circumstances with only two separate potentials. Considering EMI generated by MOSFET and IGBT during the original design stage can help designers satisfy EMC at a reasonable cost before reality. EMI forecast should be closely paid to in order to save design cycle and expense.

Purpose. Analysis of the fundamental possibility of selecting a switching device with a power supply based on an experimental measurement which allows to increase the reliability of the entire mechanism operation and significantly simplify the design.

The tests EMC in this paper underscore the importance of carefully selecting the type of switching device (IGBT or MOSFET) based on the specific requirements of different loads and switching constraints. MOSFETs are generally preferred for fast switching and low-frequency (LF) applications, while IGBTs are better suited for slower switching and high-frequency (HF) applications. Proper thermal management is also essential to ensure optimal performance. The results of these tests contribute to a better understanding of switching device performance in series chopper applications and guide design choices accordingly.

EMC measurement and standards of conducted EMI. Conducted emissions refer to disruptions in measurable electrical properties that are directly observable at the conductor level (voltage and current). These emissions encompass undesired high-frequency currents that traverse within the device, along with overvoltages that may arise at the load's terminals when powered through an extended cable [18].

To make measurements meaningful and repeatable, it is desirable to decouple the assembly under test from the network, providing a known impedance through which disturbances can be forced to pass. This is the purpose of a device known as a Line Impedance Stabilizing Network (LISN), which is inserted between the network and the assembly under test (Fig. 2).

LISN is equivalent to a filter inserted between the supply network and the input of the equipment under test. Its role is multiple: it isolates the equipment under test from the power supply network, sets the prescribed impedance at the measurement points, and channels conducted disturbances to the measurement receiver.

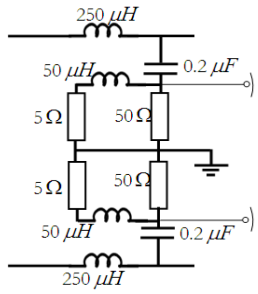

Fig. 2. Line Impedance Stabilization Network (LISN)

Conducted disturbances often pertain to high-frequency currents circulating within the device. The term high-frequency typically encompasses frequencies ranging from 150 kHz to 30 MHz, as this frequency range aligns with the bandwidth regulated by prevailing EMC standards. This current can be dissected into two modes (CM and DM), as depicted in Fig. 3.

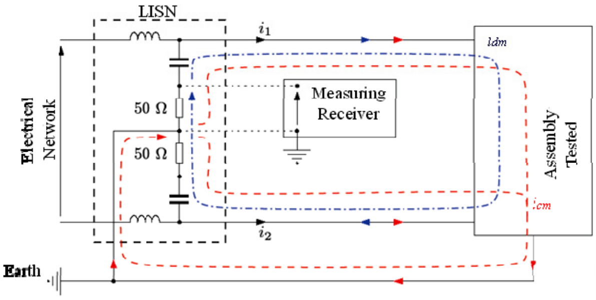

Fig. 3. High-frequency CM (I_{cm}) and DM (I_{dm}) currents

The DM current (I_{dm}) characterizes the portion of the current that forms a loop within the power conductors between the power source and the load. This is the normal current path, but the high-frequency components are undesirable.

The CM current (I_{cm}) refers to the portion of the current that flows through the ground wire. This path typically does not participate in power transfer, but it can carry high-frequency components, especially through capacitive coupling. Regardless of their coupling mode, these high-frequency currents ultimately loop back through the internal impedances of the electrical network, making their measurement dependent on the specific network configuration and layout.

All power transistors are sources of pollution due to parasitic elements coming from the power supplies themselves. Like most electrical equipment today, they must comply with EMC standards. Even if their predominant use in the industrial sector means that they can sometimes escape this constraint, their progressive use in the tertiary sector means that the normative aspect must be met, or at least anticipated. Companies specializing in the design of power supplies and, more generally, of static converters, are today faced with this type of requirement. Power transistor applications, which are now common place in many service sectors, represent some of the most complex power structures in terms of design and modeling.

Each regulatory body has a specific standard for carrying out EMC tests. Measurements are carried out in accordance with EN 55022 [19-22]. The latter imposes a specific measurement protocol. This protocol guarantees the reproducibility and reliability of measurements carried out on the equipment under test. In order to explain the layout of the various system components and the configuration of the normative measurements, we present the synoptic diagram of the test bench in Fig. 4. The conducted emission test configuration complies with EN 55022. All devices are placed on a copper ground plane.

The equipment under test is placed on a plane electrically isolated from the surrounding area.

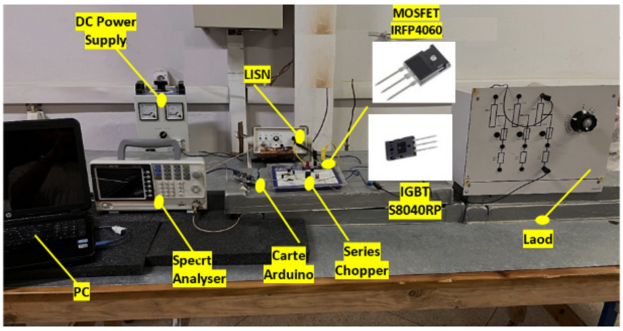

Fig. 4. EMC bench for measuring conducted EMI

In the context of conducting a comparison regarding conducted EMI in CM and DM, involving a series chopper associated with a resistive load, two static converters were utilized for reference purposes: the IGBT reference FGH40N60 and the MOSFET reference IRFP4060, along with a BYT12 diode. An experimental setup was established to assess the conducted EMI, where a chopper (Fig. 5) fed a resistive load at a continuous 24 V voltage level. The primary measurement elements included the LISN connected before the chopper, as well as a spectrum analyzer to measure the conducted disturbances in both CM and DM across various load values.

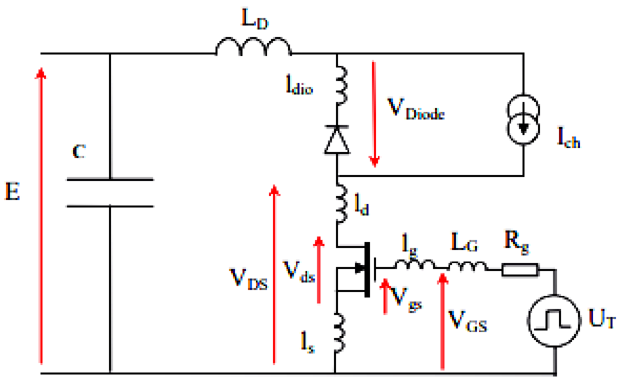

Fig. 5. Chopper (equipment under test)

We have focused on the conducted mode, which is largely responsible for the majority of disturbance phenomena generated by these devices. The distribution of CM and DM currents in the system will be presented. To illustrate their origins, CM currents are essentially transmitted via capacitive CM couplings. Conducted disturbances propagate to other parts of the system by looping through the ground.

For the analysis of EMI produced by the converter, spectral estimates must be referred to EN 55022, the standard for measuring disturbances. To comply with current regulations, a frequency range of 150 kHz to 30 MHz must be taken into consideration. The standard aims to estimate EMI in the measurement receiver at the chopper input.

A method of EMC analysis commonly used in power electronics has been employed. To illustrate this method, we will first use a chopper with the MOSFET (IRFP4060), and then the same chopper with the IGBT (FGH40N60). From there, we'll choose the analysis method and the resulting measurement tool for what would appear to be the most suitable for this study.

Results and discussion. Figures 6, 7 show the frequency spectrum of disturbances after using the MOSFET respectively in CM and DM with different loads (50 Ω, 100 Ω and 200 Ω).

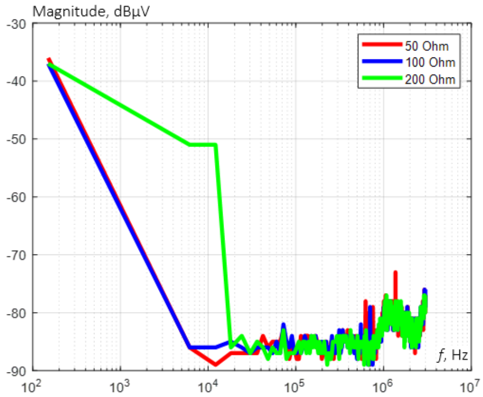

Fig. 6. CM EMI (MOSFET)

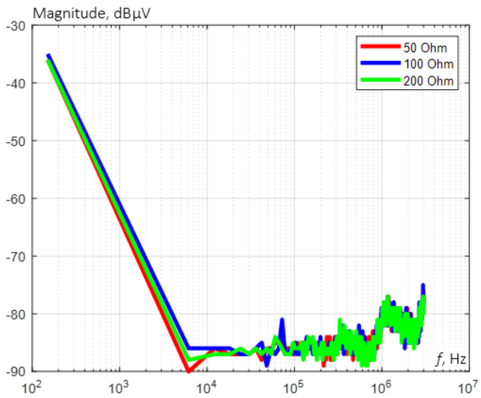

Fig. 7. DM EMI (MOSFET)

When parasitic currents flow through the links in the same direction, closing at equipotential bonding, we speak of CM. In this case, parasitic currents propagate via the parasitic capacitances created between each hot spot subject to voltage variations (MOSFET drain) and the ground plane, and via the parasitic capacitances between the semiconductor and the heat sink. These parasitic currents flow through the two parallel resistors of standardized value equal to 50 Ω.

In DM, when parasitic currents flow in both conductors. These currents are due to the switching of switch currents (MOSFET). Part of the switching current flows through the switching capacitor, and the other part through the two resistors of 50 Ω in series.

In the linear amplification region of the MOSFET transistor, when the input voltage exceeds the threshold voltage, a small current begins to appear at the output. This current creates a voltage across the resistor, causing the output voltage to decrease. Conducted EMI (CM and DM) is very small. Transitioning to the linear region, we observe similar conducted disturbances in both CM and DM. However, once the output current reaches a certain value, the V_{DS} voltage drops below the $V_{GS} - V_{th}$ voltage, as seen in the case of a load equal to 50 Ω in Fig. 8.

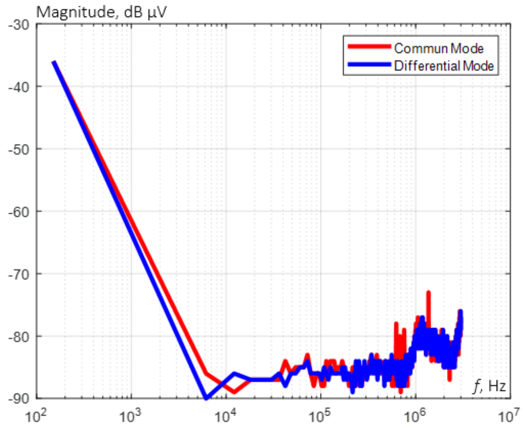

Fig. 8. CM/DM EMI (MOSFET)

As the load increases, the occurrence of interference spikes in the DM increases in the first operating region (switching state or closure) of the switch. This is due to rapid voltage fluctuations exceeding the threshold voltage and significant current appearing at the switch's output (for a load of 200 Ω) (Fig. 9). In contrast, the MOSFET does not exhibit any CM propagation during the switching phase, which is similar to that of the 50 Ω load (Fig. 8).

The conducted interference diagrams in CM observed for the IGBT power switch are nearly identical for different loads (Fig. 10). However, there is a notable interference peak for the 50 Ω and 100 Ω loads compared to the 200 Ω load.

In this study, the behavior of the EMIs (CM and DM) from the two static converters is nearly the same, but with different amplitudes and peaks, and higher with the lower load.

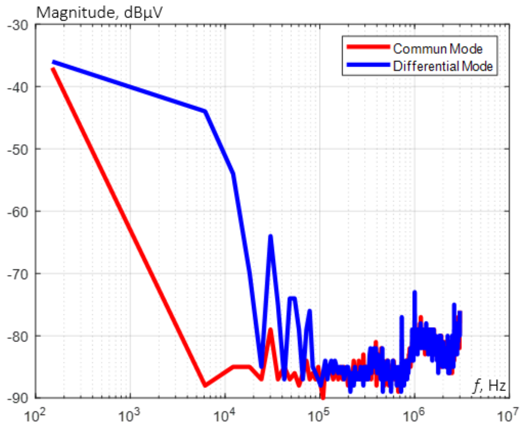

Fig. 9. CM/DM MOSFET

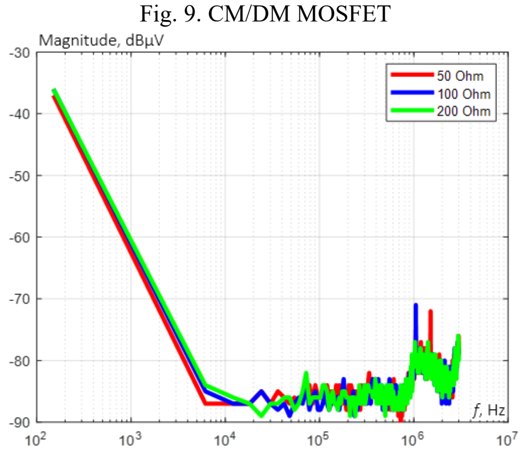

Fig. 10. CM EMI IGBT

In DM, the impedance of the load can play a crucial role. An increase in the resistive load can lead to an increase in differential impedance, which can influence the time required for the current to reach its nominal level in DM. On the other hand, higher loads (200 Ω load in our test) can generate more heat, which can affect the performance of the IGBT device. Elevated temperatures can influence the switching behavior (Fig. 11).

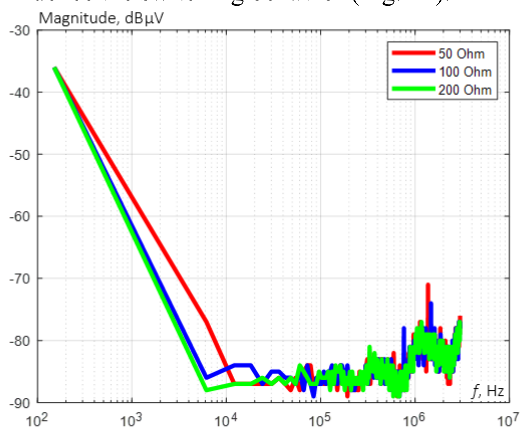

Fig. 11. DM EMI IGBT

The IGBT power switch behaves in a similar manner in both CM and DM for a 50 Ω load (Fig. 12) and a 200 Ω load (Fig. 13). However, for a low load, the IGBT takes longer to transition from the first region to the linear region.

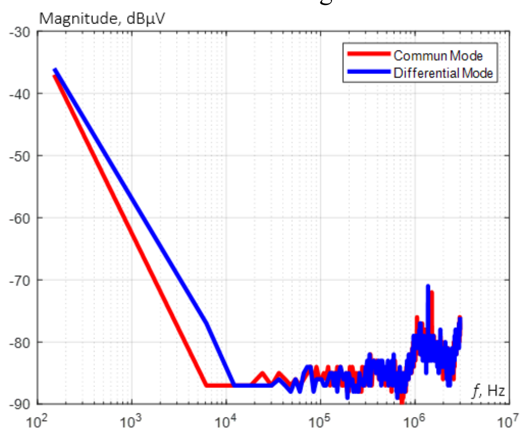

Fig. 12. CM/DM IGBT

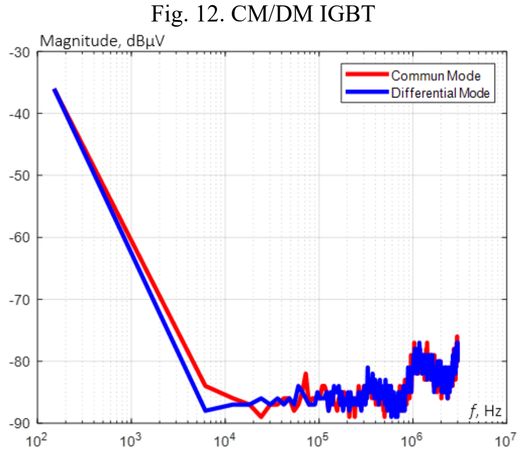

Fig. 13. CM/DM IGBT

In Fig. 14, 15, for a 50 Ω resistive load, both power switches exhibit similar interference patterns. However, in DM, the IGBT may show a more significant switching delay compared to the MOSFET.

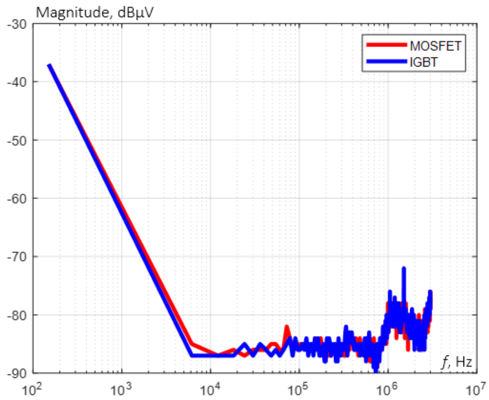

Fig. 14. CM MOSFET/IGBT

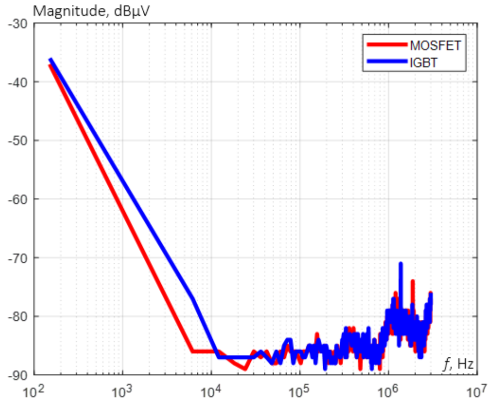

Fig. 15. DM MOSFET/IGBT

This last difference can be attributed to the intrinsic switching times of the two devices. The MOSFET, typically being faster, responds more swiftly in this context, while the IGBT may require more time to reach its switching state in DM with this load.

The conducted (CM and DM) interference tests using a series chopper employing both an IGBT and a MOSFET revealed several key observations.

When the load is increased to 200 Ω, the conducted disturbances in CM (Fig. 16) remain the same as those for a 50 Ω load in both operational regions for both switches. However, in the case of DM (Fig. 17), a significant current appears across the terminals of the load when the input voltage exceeds the threshold voltage for the MOSFET. The IGBT, on the other hand, does not reach saturation in this region.

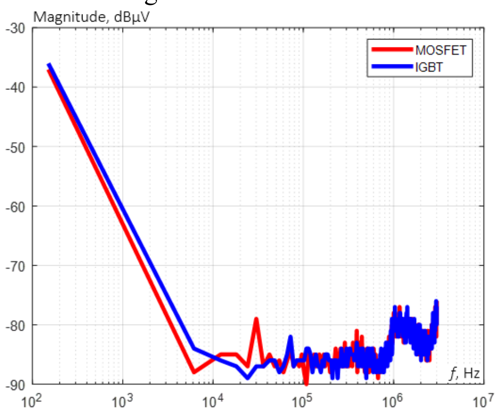

Fig. 16. CM MOSFET/ IGBT

The main difference between IGBTs and MOSFETs is that IGBTs have an additional p-n junction compared to MOSFETs, which gives them the properties of both MOSFETs. The least disruptive power switch is the one that produces the least amount of transients when it is turned on or off. These transients can cause damage to sensitive electronic equipment.

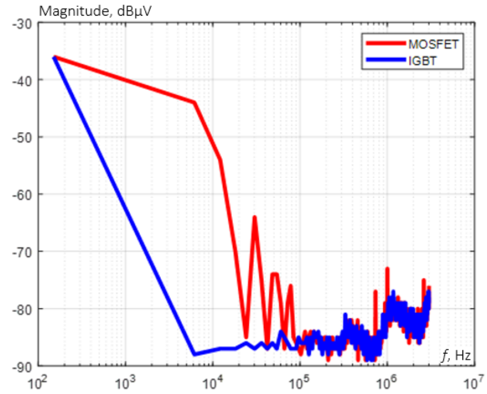

Fig. 17. DM MOSFET/ IGBT

Conclusions.

1. The difference between using an IGBT and a MOSFET is that the IGBT tends to have smoother switching, resulting in fewer high harmonics and less electromagnetic interference (EMI) during switching. This can be advantageous in terms of electromagnetic compatibility as smoother current transitions reduce the potential for EMI emissions. Conversely, MOSFETs, especially when used in high-speed switching applications, can generate higher peaks of EMI due to their rapid switching in the low-frequency (LF) and high-frequency (HF) ranges.
2. MOSFET is better suited for fast switching and low-frequency applications, whereas IGBT is more suitable for LF and HF. The difference in behavior between the IGBT and MOSFET is linked to their intrinsic switching characteristics. MOSFET tend to have shorter switching times, making them faster in responding to variations in load and voltage. Conversely, IGBT may exhibit longer switching delays.
3. The load defines the switch's electrical characteristics, such as rated power, current and voltage. It is important to choose a switch whose characteristics correspond to the load to which it will be connected.
4. Impact of the load value: played a critical role in test results. Resistive loads of varying values influenced interference levels and observed switching delays.
5. Thermal effects: tests also demonstrated that higher loads could generate more heat, potentially affecting the performance of switching devices, particularly IGBT.

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Conflict of interest. The authors declare no conflict of interest.

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