Mitigating EMI in Gate Driver Circuits

A Comparative Analysis of Transformer Designs

WHITE PAPER

Introduction

As gate driver-based converters continue to gain traction across a wide range of industrial applications, effective management of Electromagnetic Interference (EMI) has become increasingly critical. The high frequency switching characteristics of modern power electronic systems often leads to elevated levels of conducted EMI, posing challenges to Electromagnetic Compatibility (EMC) and overall system reliability.

This white paper provides a comparative analysis of how transformer topology influences conducted EMI emissions in gate driver applications. Specifically, the study contrasts a traditionally used planar transformer with a concentric wound transformer. All measurements were performed using an internal evaluation board to ensure consistency and comparability across test conditions.

Background

High voltage power is a cornerstone in clean energy delivery through electrification, particularly in areas such as e-mobility and renewable energy infrastructure. Wide band gap semiconductors enable efficient high frequency-high voltage operation due to their superior switching characteristics and low conductive losses. Silicon Carbide (SiC) modules require a positive gate voltage (15 V) to turn on the device and a negative voltage (typical -5 V) to ensure reliable turn off by reverse-biasing the gate junction.

To supply these voltages, gate driver ICs typically use isolated power delivery through the use of push pull drivers, LLC converters or flyback converters. Isolation is achieved using transformers designed with sufficient insulation, creepage and clearance, to meet safety and regulatory standards. Operating at elevated switching frequencies (300-500 kHz) allows for more compact designs and higher power levels but it also increases the risk of electromagnetic emissions.

While the gate driver represents only one part of the overall power converter, it can be a significant source of common-mode emissions. One primary contributor is the isolation transformer which can introduce common-mode currents into the ground plane due to parasitic elements such as interwinding capacitance and leakage inductance.

Planar transformers offer several advantages in this context:

A. **Reduced interwinding capacitance** – minimizes capacitive coupling, which can reduce common-mode noise due to dielectric barrier between turns.
B. **Lower profile** - compared to traditional concentric wound transformers, the planar design offers a reduced vertical height, making it more suitable for compact or low-clearance applications.
C. **Improved manufacturing consistency** – PCB-based windings enable high precision and low unit variations, leading to more consistent EMI performance.

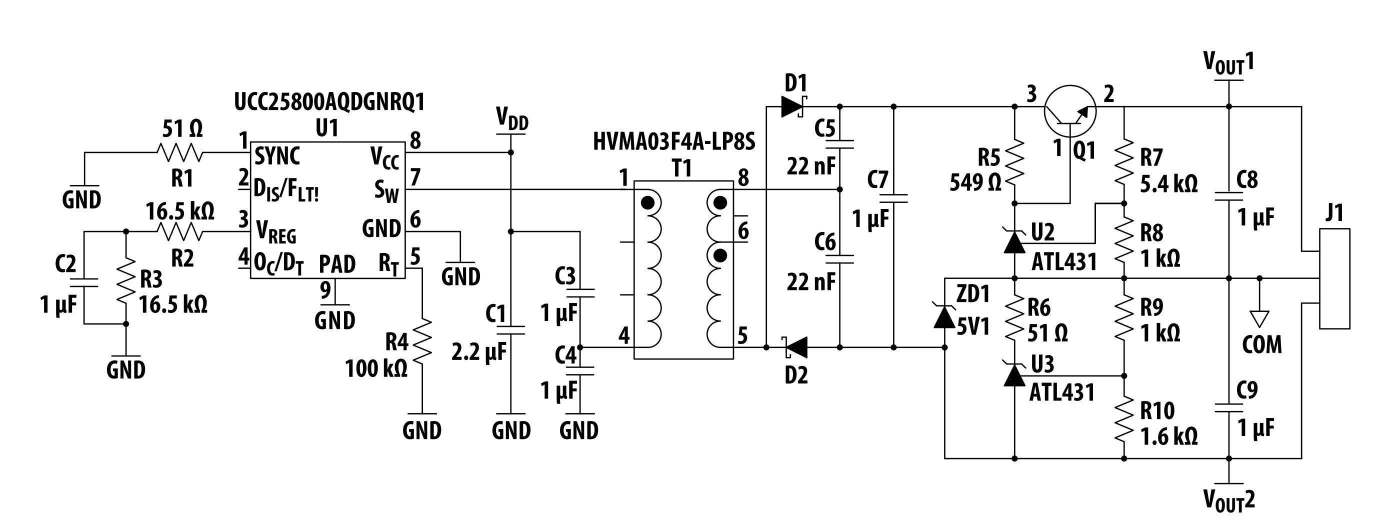

Figure 1. Gate Driver Circuit Diagram Showing Bourns® Transformer HVMA03F4A-LP8S

Background (Continued)

The objective of this paper is to present the results from a comparative study between a planar transformer and a traditional concentric-wound transformer, focusing on the impact on conducted EMI emissions in gate driver applications to ensure consistency and reliability. All measurements were performed using a gate driver evaluation board developed by Bourns. The board is powered by a clean 12 V DC source from a battery to minimize external noise. Line Impedance Stabilization Networks (LISNs) were connected to both the positive and negative supply lines to provide a defined impedance and to enable precise EMI measurements.

Key components on the evaluation board include a buck regulator, isolated gate driver ICs (UCC23500), and linear regulators that generate isolated -4 V/+16 V rails for switch operation. These elements are highlighted in red on the board for clarity (Fig.3). This setup ensures a controlled environment to evaluate the impact of transformer topology on conducted EMI emissions in gate driver applications. The circuit operates at a switching frequency of 1 MHz. At this frequency, increased interwinding capacitance in the transformer can significantly degrade EMI performance due to enhanced common-mode noise coupling.

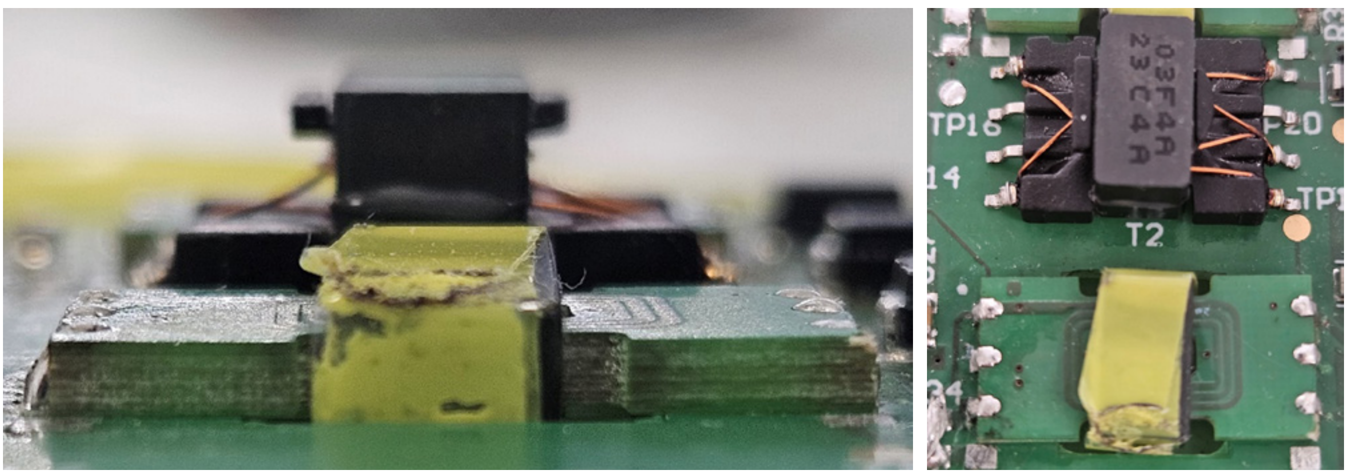

Figure 2. Size comparison of planar vs concentric wound transformer

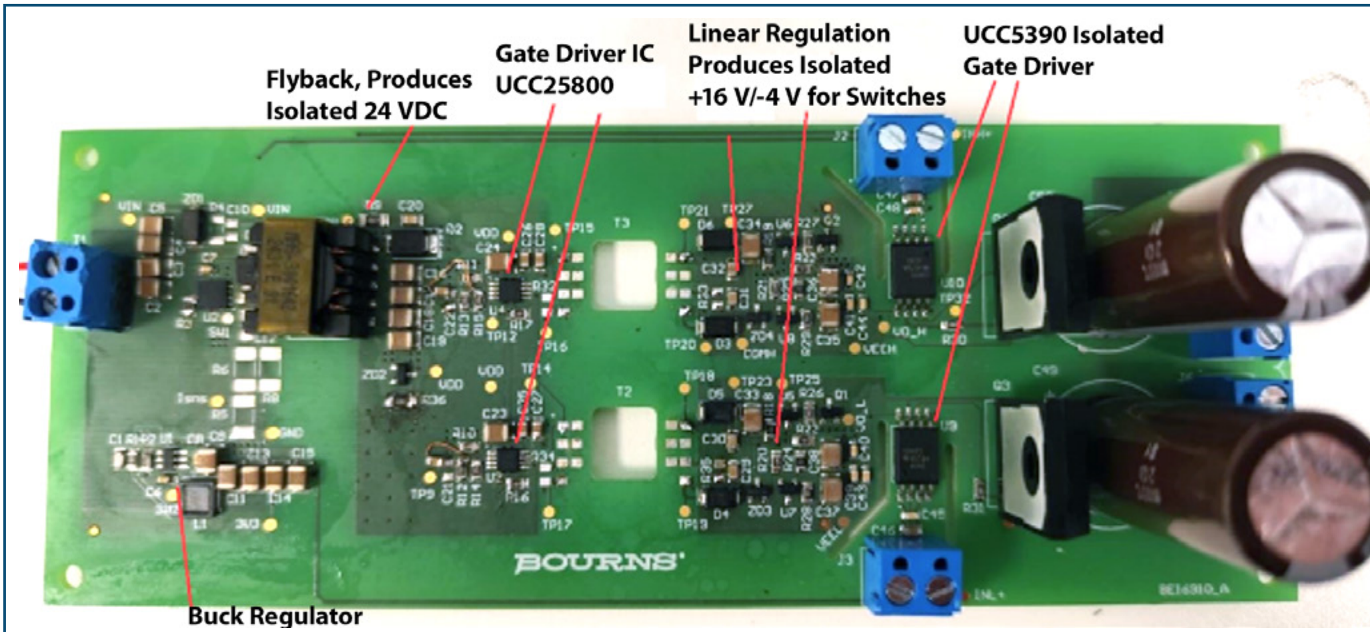

Figure 3. Evaluation board description

Test Method and Setup

1. Devices Under Test (DUTs) – this study compares two transformer topologies: a conventional concentric-wound transformer and a planar transformer.
2. Test Conditions – each DUT is evaluated under identical operating conditions.
3. EMI Measurement Bands – conducted and radiated emissions are recorded across the five frequency bands:
   - 9 kHz –150 kHz
   - 150 kHz – 30 MHz
   - 30 MHz – 300 MHz
   - 300 MHz – 1000 MHz
   - 9 kHz – 1000 MHz.

The results were plotted as dBµV vs. frequency to visualize and compare performance.

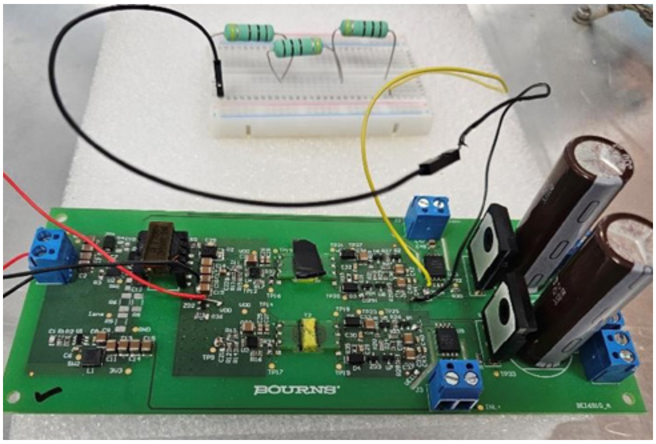

Figure 4. Evaluation board in test setup

Test and Measurement Equipment

1. EMI Test Receiver - connected to the LISN to capture conductive emissions from the DUT.
2. Detection Mode – all measurements were performed using the peak detector mode of the receiver.

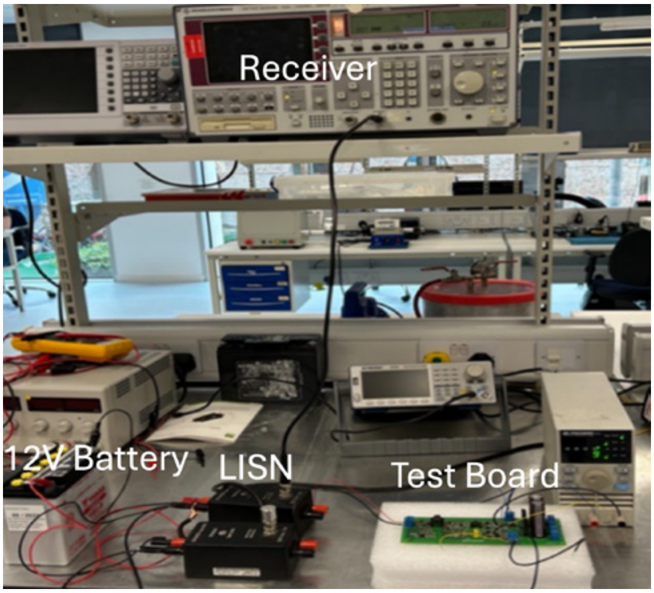

Figure 5. Full test setup

Results

Scenario 1: 9 kHz – 150 kHz

Conducted EMI measurements in the 9 kHz to 150 kHz low frequency band indicate relatively low emission levels for both transformer topologies. The measured signal amplitudes remain mostly below -10 dBµV, demonstrating minimal low-frequency noise contribution from the gate driver transformers.

These results suggest that transformer topology has a limited impact on EMI performance in this range, and that both DUTs operate well with applicable emission standards.

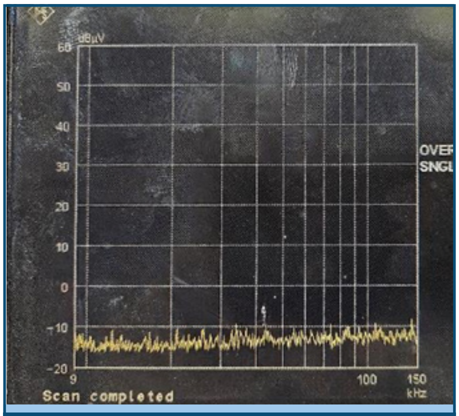

Figure 6. 9 kHz – 150 kHz Floor

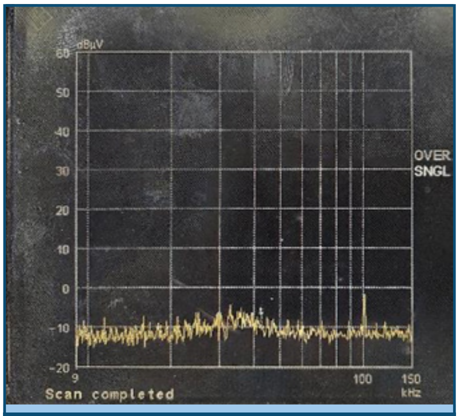

Figure 7. DUT 1 9 kHz – 150 kHz

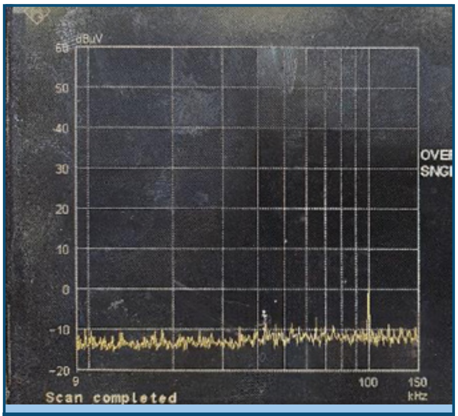

Figure 8. DUT 2 9 kHz – 150 kHz

Scenario 2: 150 kHz – 30 MHz

In the 150 kHz to 30 MHz frequency, both transformer topologies exhibit a prominent emission peak of approximately 50 dBµV at the fundamental switching frequency of 1 MHz. Additional peaks at harmonic frequencies further confirm the presence of periodic switching noise inherent in high-frequency operation.

DUT 2 (Fig.11), which utilizes a planar transformer architecture, demonstrates improved performance compared to DUT 1, which uses a conventional concentric-wound transformer (Fig. 10). DUT 2 exhibits emission levels that are up to 10 - 15 dBµV lower at several higher frequency points, indicating improved suppression of conducted emissions in this range.

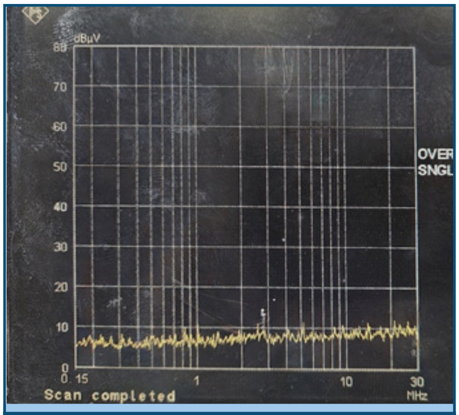

Figure 9. 150 kHz – 30 MHz Floor

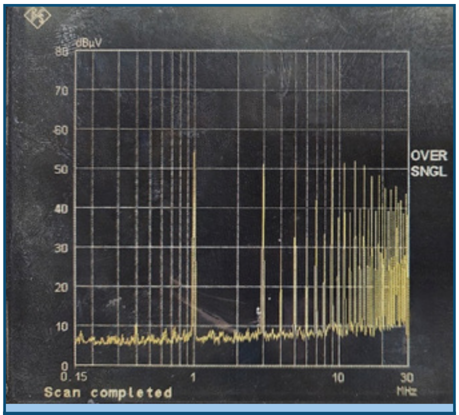

Figure 10. DUT 1 150 kHz – 30 MHz

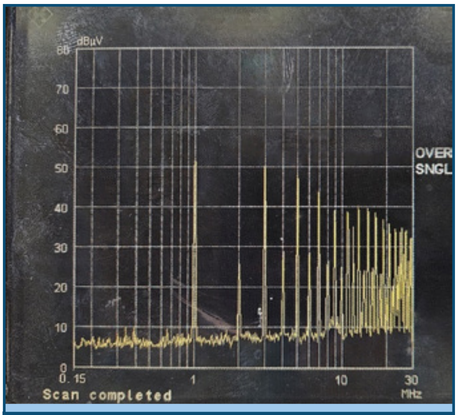

Figure 11. DUT 2 150 kHz – 30 MHz

Results (Continued)

Scenario 3: 30 MHz – 300 MHz

DUT 2 continues to exhibit lower overall emission levels across the 30 MHz – 300 MHz frequency band, further reinforcing its superior electromagnetic performance. These results validate the advantages of planar transformer architecture in high-frequency gate driver applications, particularly in terms of reducing common-mode conductive emissions. Both transformers exhibit a noticeable increase in emissions between 150 MHz and 200 MHz, suggesting the presence of a common resonance or coupling mechanism within this frequency range.

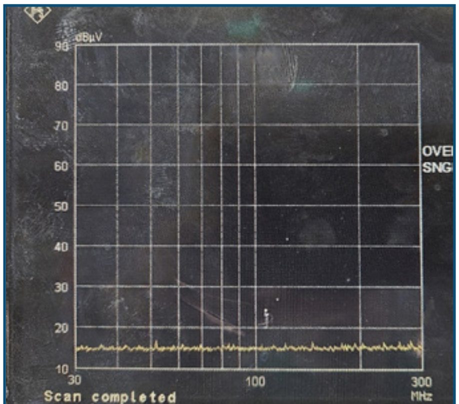

Figure 12. 30 MHz – 300 MHz Floor

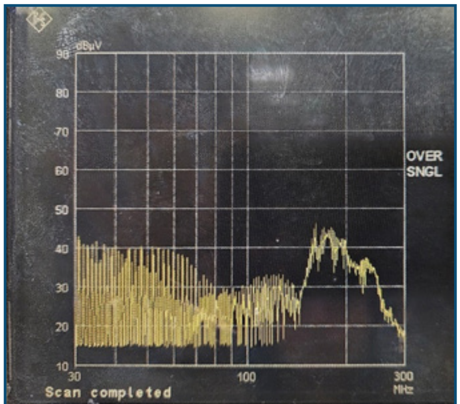

Figure 13. DUT 1 30 MHz – 300 MHz

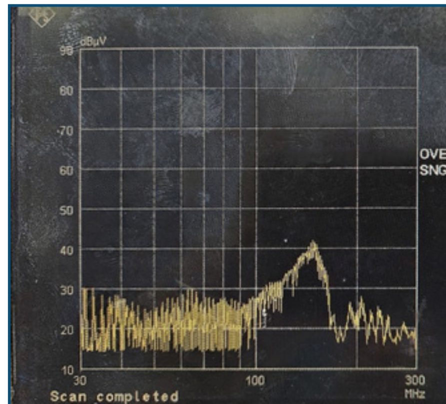

Figure 14. DUT 2 30 MHz – 300 MHz

Scenario 4: 300 MHz – 1000 MHz

Similar to the low frequency band, the high frequency range (300 MHz - 1000 MHz) exhibits broadly comparable performance across all tested transformers. This consistency indicates that transformer geometry and interwinding capacitance have a reduced impact on conducted emissions at higher frequencies, particularly beyond 600 MHz.

These findings suggest that while transformer topology plays a critical role in EMI suppression at lower and mid-range frequencies, its influence diminishes in the ultra-high frequency domain, where system-level design considerations become increasingly dominant.

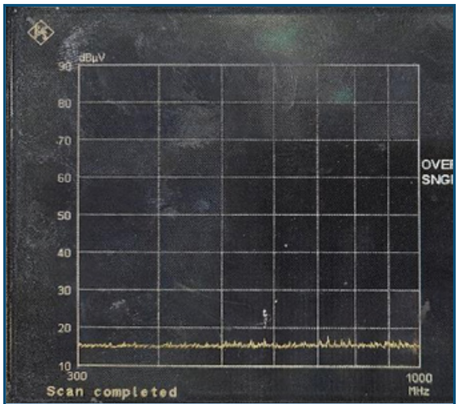

Figure 15. 300 MHz – 1000 MHz Floor

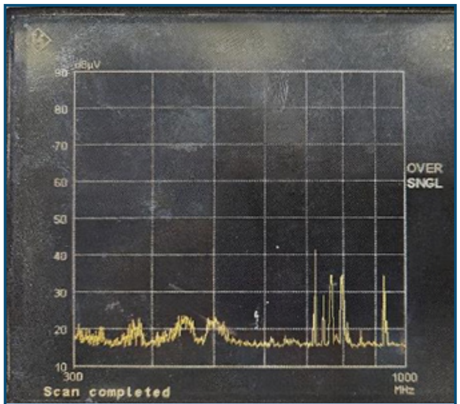

Figure 16. DUT 1 300 MHz – 1000 MHz

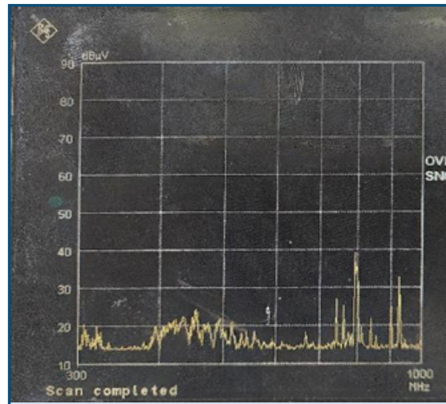

Figure 17. DUT 2 300 MHz – 1000 MHz

Results (Continued)

Scenario 5: 9 kHz – 1000 MHz

Across the full frequency spectrum from 9 kHz to 1000 MHz, DUT 2 (Fig. 20) delivers the lowest or comparable emission levels. Its performance is particularly notable in the critical 1 MHz to 100 MHz range, where switching harmonics and conducted noise are most prominent in gate driver applications.

Within this band, DUT 2 outperforms DUT 1 by a significant margin, demonstrating both lower peak amplitudes and a smoother spectral profile. These results suggest that the planar design offers enhanced suppression of high-frequency noise, likely attributed to its optimized winding geometry, reduced parasitic capacitance, and improved shielding characteristics.

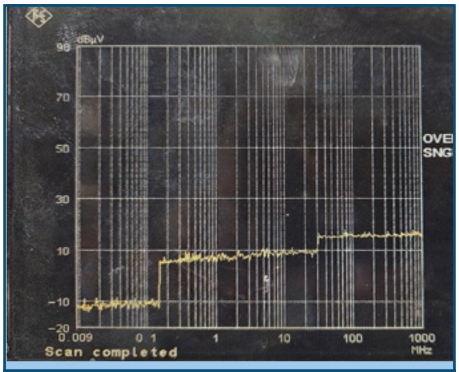

Figure 18. 9 kHz – 1000 MHz Floor

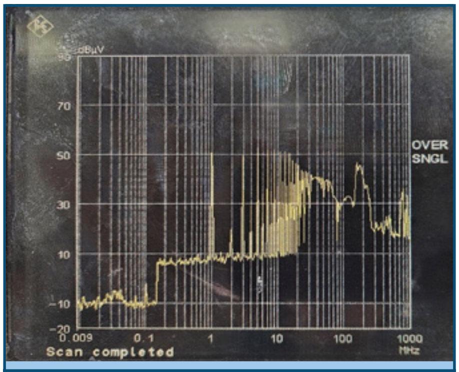

Figure 19. DUT 1 9 kHz – 1000 MHz

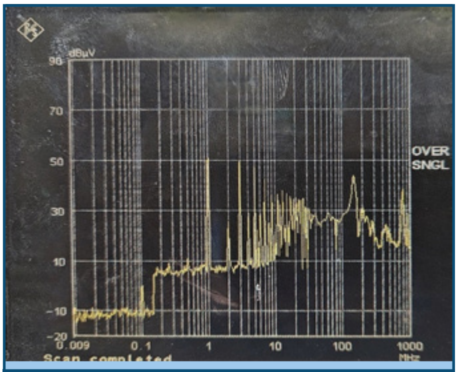

Figure 20. DUT 2 9 kHz – 1000 MHz

Conclusion

This study demonstrates that transformer topology significantly influences the conducted EMI performance of gate driver circuits. While both transformer variants show comparable behavior in the low (9 kHz – 150 kHz) and high (300 MHz – 1000 MHz) frequency bands, marked differences emerge in the mid-frequency ranges between 150 kHZ and 300 MHz. The planar transformer (DUT 2) consistently exhibits lower EMI emissions than DUT 1 across the most critical frequency bands, particularly between 1 MHz and 100 MHz, where switching noise and harmonics are most pronounced.

This superior performance underscores the effectiveness of planar designs in suppressing high-frequency noise coupling. Additionally, the lower profile of the planar transformer makes it especially suitable for space-constrained applications. Overall, DUT 2 proves to be the most effective solution for reducing conducted EMI, positioning it as a strong candidate for designs requiring stringent EMC compliance.