# Enhanced Hardware Optimization for RE102 Emission Suppression in POSAFE-Q PLC

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***Keywords :*** Nuclear Power Plants, Safety PLC, POSAFE-Q, EMI Suppression, EMC Testing

## 1. Introduction

The POSAFE-Q PLC is designed to comply with both the military standard MIL-STD-461G and the nuclear power plant EMC standard Reg. Guide 1.180 Rev. 2, and it has successfully passed electromagnetic compatibility (EMC) testing. The requirements of MIL-STD-461G have been significantly enhanced in response to the latest technological and environmental changes, and Reg. Guide 1.180 Rev. 2, the EMC standard for the nuclear industry, has been revised accordingly. The latest revision imposes more stringent test conditions across various frequency bands, thereby strengthening overall electromagnetic emission (EMI) testing.

Nuclear power plants are particularly critical environments for safety and reliability, and electromagnetic interference (EMI) generated by essential instrumentation and control (I&C) systems can lead to equipment malfunctions or signal distortion. Therefore, effectively suppressing EMI and ensuring EMC performance are essential to maintaining operational safety and continuous operation in nuclear power plants.

Although the POSAFE-Q PLC previously met RE102 requirements by optimizing grounding and cable configurations under typical test conditions, the increasingly diverse operational environments in nuclear power plants and the stricter demands introduced by Reg. Guide 1.180 Rev. 2 have called for a more robust design strategy. To that end, this paper presents a hardware-level approach that directly suppresses radiated emissions at their source, thereby enhancing overall EMI performance. In particular, the effectiveness of this improvement is quantitatively demonstrated by comparing the analog module's radiated electric field waveforms before and after the modification. Additionally, practical design and test approaches are presented to further strengthen the EMC performance of the POSAFE-Q PLC.

## 2. Methods and Results

In this section, we introduce the RE 102 test, analyze the EMI characteristics of the POSAFE-Q PLC analog module before and after hardware improvements, and demonstrate the effectiveness of these improvements using example data.

### *2.1 RE 102 Test Overview*

The RE 102 test evaluates radiated emissions from 2 MHz to 10 GHz and is a key requirement of both the military standard MIL-STD-461G and the nuclear power plant EMC standard, Reg. Guide 1.180. In earlier guidance (Rev.1), this test typically covered up to around 1 GHz, but the latest revision (Rev.2) extends the upper frequency limit to 10 GHz, imposing stricter demands in higher frequency ranges. Although a 3 dB margin beyond the emission thresholds shown in Fig. 1 had already been applied under Rev.1, Rev.2 continues to enforce this margin while widening the test spectrum. These tightened requirements substantially increase the challenge of controlling electromagnetic interference (EMI) and underscore the importance of robust mitigation strategies for high-frequency noise.

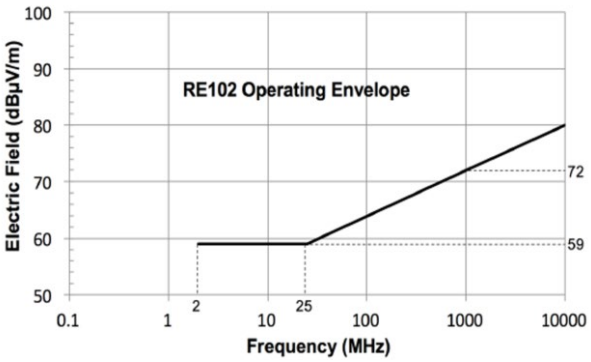


Fig. 1. Electric-Field Radiated Emissions Envelopes

### *2.2 Analog Module EMI Characteristics Before Improvement*

Preliminary RE 102 testing revealed EMI performance weaknesses in the analog modules of the POSAFE-Q PLC. In the process of amplifying a 5 V input voltage to 15 V via a DC-DC converter, these modules utilize high-speed switching circuits, whose switching frequency and harmonic components were identified as the primary cause of excessive electromagnetic emissions. Fig. 2 shows the radiated electric field spectra of the four analog modules prior to improvement. In certain frequency ranges, peaks exceeded the baseline threshold, resulting in noncompliance with RE 102 test specifications.

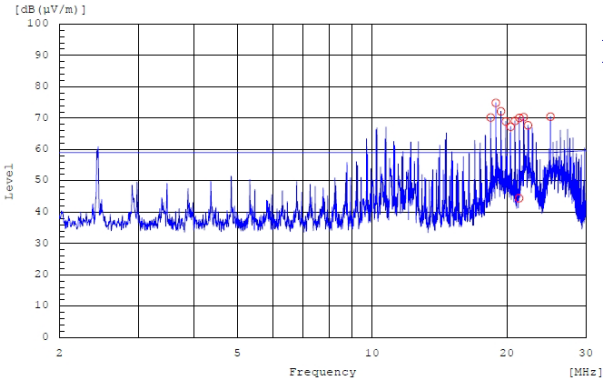


Fig. 2. Radiated Emission Spectrum (2 MHz ~ 30 MHz) of Four Pre-Improvement PLC Analog Modules

### *2.3 Hardware Improvement Method and Post-Improvement EMI Analysis*

To address the EMI issue, a hardware enhancement was made by inserting 47 μH chip inductors at the DC-DC converter outputs (Vout+, Vout-, COM), as shown in Fig. 3(a). These inductors provide high impedance in the high-frequency band, effectively suppressing switching frequency and harmonic components. Moreover, their differential configuration allows noise currents in opposite phases to cancel each other out, thereby greatly reducing electromagnetic emissions. Fig. 3(b) shows the actual hardware module, where three chip inductors can be seen around the DC-DC converter—one inductor for each output pin.

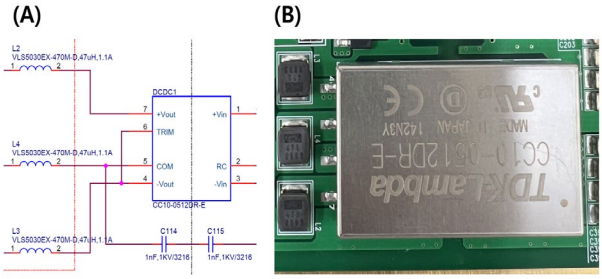


Fig. 3. Hardware Improvements of PLC Analog Modules for EMI Reduction

Measurements in the 2 MHz ~ 30 MHz range after this modification (see Fig. 4) indicate that the overall radiated electric field level decreased by approximately 10 dB. This reduction is attributed to the effective suppression of the converter's switching frequency and its harmonic components by the inductors. Furthermore, repeated tests confirmed a similar level of EMI reduction, demonstrating that this hardware improvement provides a reliable and stable EMI mitigation solution.

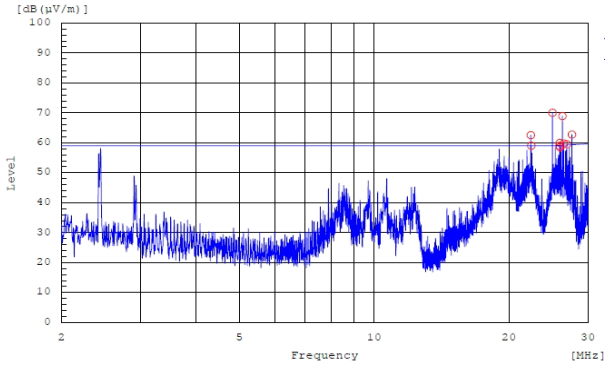


Fig. 4. Radiated Emission Spectrum (2 MHz ~ 30 MHz) of Four Post-Improvement PLC Analog Modules

### *2.4 POSAFE-Q PLC EMC Test Configuration and Final Evaluation*

Fig. 5 shows the final EMC test configuration of the POSAFE-Q PLC, with a Road antenna deployed for RE 102 (2 MHz ~ 30 MHz) band measurements.

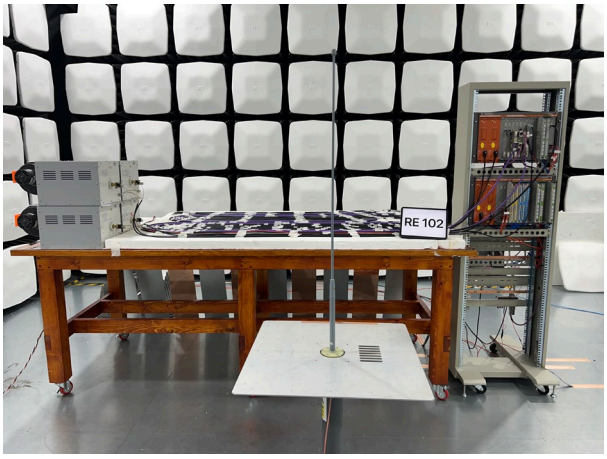


Fig. 5. POSAFE-Q PLC EMC Test Configuration and RE 102 Road Antenna (2 MHz ~ 30 MHz)

Fig. 6 presents the RE 102 (2 MHz ~ 30 MHz) measurement results for the POSAFE-Q PLC equipped with four improved analog modules. The results confirm that these improved modules meet stricter EMC criteria than before, indicating that the overall EMI suppression performance and stability of the POSAFE-Q PLC can be maintained under real-world operating conditions.

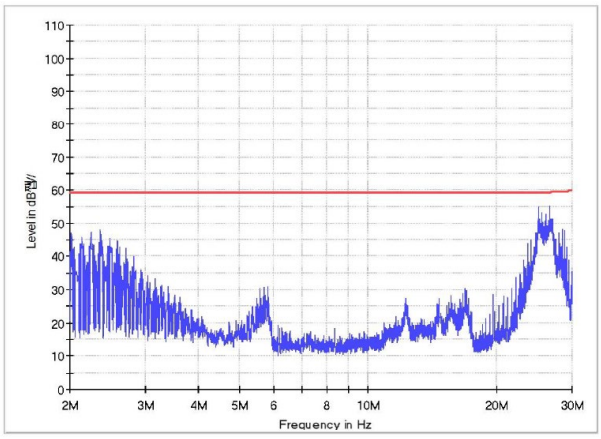


Fig. 6. Final RE 102 Test Results (2 MHz ~ 30 MHz) of the POSAFE-Q PLC After the Improvement of Four Analog Modules

## 3. Conclusions

Through hardware improvements to the four analog modules, the POSAFE-Q PLC demonstrated excellent electromagnetic emission performance in the RE 102 test environment. This study clearly validated the effectiveness of these hardware modifications by comparing waveforms before and after the improvements, and it is expected to make a substantial contribution to future design and testing approaches aimed at further enhancing EMC performance. Looking ahead, to fully address the more stringent requirements of Reg. Guide 1.180 Rev. 2, additional hardware optimizations and EMI evaluations will be extended to other modules within the POSAFE-Q PLC. By continuously strengthening the design – including advanced filtering, shielding techniques, and layout refinements across all system components – the POSAFE-Q PLC can maintain robust compliance under diverse operational conditions and ensure an even greater margin of safety in nuclear power applications.

## REFERENCES

[1] U.S. NRC Regulatory Guide 1.180 (Rev. 2, 2019), “Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems.”
[2] MIL-STD-461G (2015), “Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.”