Application Note

10 BASE-T1L Ethernet EMI and EMC Test Results

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ABSTRACT

The document describes a series of Electromagnetic Interference (EMI)/Electromagnetic Compatibility (EMC) measurements performed on the TIDA-010261 board, a Sitara-based microcontroller development platform for the DP83TD510E Single Pair Ethernet PHY. The goal was to identify sources of EMI and EMC issues. The tests revealed excessive emissions in the frequency range of 100MHz to 300MHz, likely caused by power supply noise, SD-card clocking, and internal charger-pump noise generated by diodes. To mitigate this issue, adjustments were made to the PCB design, including shielding, trace length matching, and using an inner EMMC. The final results showed significantly reduced emissions, meeting CISPR 32 standards.

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1 Introduction

This document is a detailed technical report on the Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) testing results for a 10 BASE-T1L Ethernet reference design, TIDA-010261. The report covers various aspects of EMI/EMC testing, including:

1. **Introduction**: Overview of EMI/EMC testing concepts and their importance in product development.
2. **Test Setup**: Description of the test setup for radiated emissions (RE), conductive emissions (CE), and electromagnetic susceptibility (EMS) tests, in accordance with CISPR 32 and IEC standards.
3. **Radiated Emissions Test Results**:
   - Figures 6-15 to 6-25 display plots of radiated emission results for Class A and Class B devices at various distances from the antenna.
   - Table 6-6 lists CISPR 32 FAR test result data for shielded SPE cable and unshielded twisted pair frequencies, including minimum and maximum measured values.
4. **Conducted Emissions Test Results**: Figures 6-16 to 6-18 depict conducted emission results at 50kHz and 30MHz frequency ranges for Class A and Class B devices using CISPR 32 measurement standards.
5. **Electromagnetic Susceptibility (EMPS) Test**:
   - Figures 9-36 illustrate the setup for radiated immunity tests to investigate susceptibility of TIDA-010261 to electromagnetic sources.
6. **Results Analysis**: Discussion on EMI/EMC test data, indicating successful passes in all conducted and radiated emission tests but potential opportunities for improvement (for example., using internal SD Cards or matching circuit traces).
7. **Summary**: Recap of the EMI/EMC testing results, highlighting achievements and avenues for process enhancement.

Some takeaways from this document are:

- The 10 BASE-T1L Ethernet reference design demonstrated good success in passing most EMI/EMC tests.
- There is an opportunity to reduce noise radiation caused by internal high-speed components such as SD Cards.
- Optimizing the trace length and impedance in electronic circuit design can help mitigate EMI behavior.

This technical report is useful for engineers working on product development in a range of industries, particularly those dealing with complex electronics and needing guidance on applying electromagnetic susceptibility testing to the systems.

2 System Description

This design implements a digital back end for sensors and actuators. For communication to upper layers, the design makes use of 10BASE-T1L SPE allowing up to 1km of cable length with 10Mbps data throughput. Two options are available to power the design, either:

1. Acting as a PoDL PD being powered from the Ethernet lines
2. Operating in stand-alone mode by attaching a 24V power supply

The Sitara™ AM2434 processor on the board allows implementation of powerful sensors or actuators with the possibility to perform processing of data, like fast Fourier transform (FFT) calculations directly on the edge. The interface option of having a PHI and BoosterPack connector, allows the design to connect to the *Four-Channel Synchronous IEPE Vibration Sensor Interface Reference Design* design guide which implements a four-channel integrated electronics piezoelectric (IEPE) vibration sensor front end. In the example shown in this design guide, the vibration sensor can be used for not only capturing vibration data of four analog channels, but also processing the data, like calculating an FFT and make decisions based on the results.

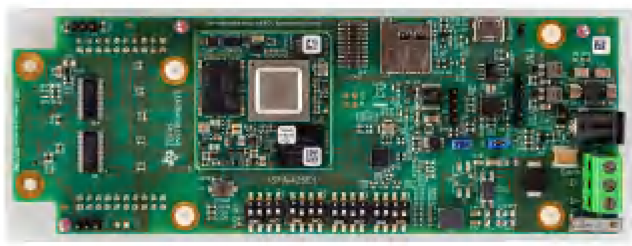

Figure 2-1. PCB TIDA-010261

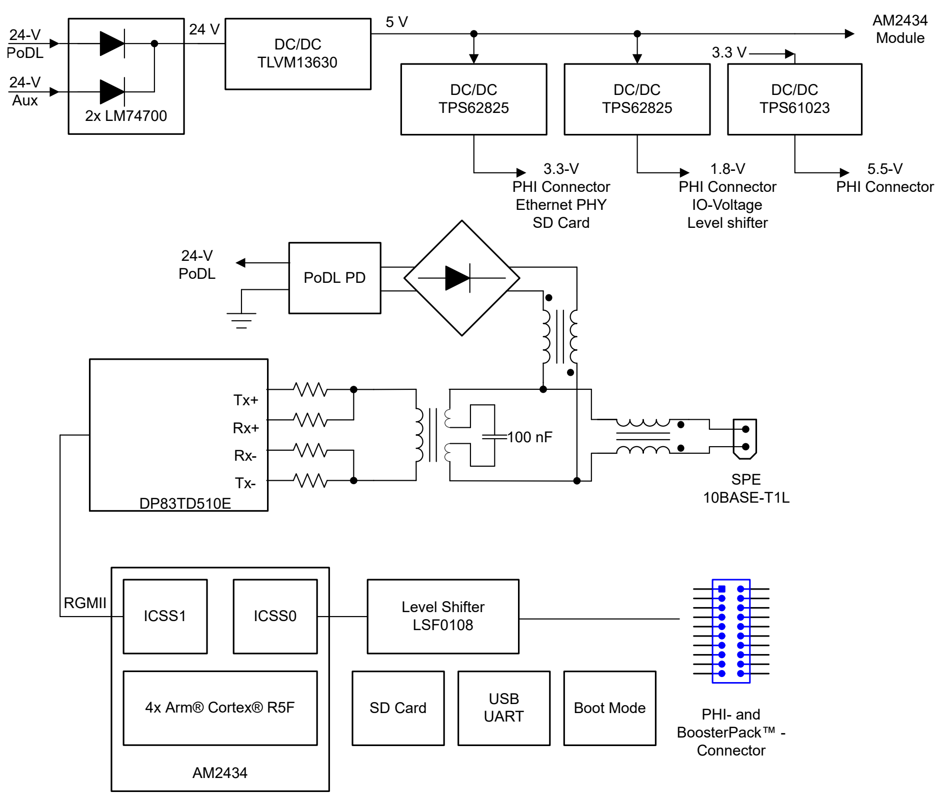

Figure 2-2. TIDA-010261 Block Diagram

3 Classification

The TIDA-010263 test board is designed to meet the EMC and EMI test standard and criteria for industrial applications. According to the standard, the following tests are selected:

- IEC 61000-4-2: Electrostatic Discharge (ESD)
- IEC 61000-4-3: Radiated Immunity (RI)
- IEC 61000-4-4: Electrical Fast Transients (EFT)
- IEC 61000-4-5: Surge Immunity (SI)
- IEC 61000-4-6: Conducted Immunity (CI)
- IEC 61000-6-3 EMCL DC Conducted Voltage Emissions
- CISPR 32: Radiated Emissions for EMI from industrial, scientific and medical (ISM) equipment

Table 3-1. Classification Matrix

Performance (Acceptance Criterion)	Description
A	Module shall continue to operate as intended. No loss of function, performance and no Ethernet packets are corrupted, even during the test
B	Temporary degradation of performance during test is accepted. After the test, module shall continue to operate as intended without manual intervention
B*	Module shall continue to operate as intended. No loss of function or performance even during the test. Some data packets can be missing, but communication is not completely link loss
C	During the test, loss of functions accepted, but no destruction of hardware or software. After the test, module shall continue to operate as intended automatically, after manual restart, or power off, or power on. Not self-recoverable

Definition of **Criterion A** is customer-dependent:

- For communication interfaces often less than three consecutive errors are still considered Criterion A.
- Customers typically test **twice the standard voltages.**
- Achieving **criterion A, especially with EFT is a competitive advantage.**

-> Yields to more robust system with better performance and less downtime in a harsh industrial environment

4 EMI and EMC General Overview

EMI (Electromagnetic Interference) and EMC (Electromagnetic Compatibility) tests are essential procedures in electronic and electrical engineering.

4.1 EMI

Electromagnetic interference (EMI) refers to unwanted electromagnetic disturbances emitted by an electrical or electronic device, which can affect the performance of nearby devices or communication systems. For example, *an inadequately shielded device can generate radio frequency interference that disturbs nearby electronic equipment* (*What's the Difference Between EMI and EMC?*).

4.2 EMC

Electromagnetic Compatibility (EMC) Is the ability of an electronic device to function correctly in the environment without emitting harmful interference or being affected by electromagnetic emissions from other devices. Essentially, *EMC makes sure that a device can coexist with other equipment without causing or experiencing disruptions* (*What are EMC and EMI?*).

4.3 EMI and EMC Testing

EMI/EMC testing is conducted to make sure that products meet regulatory standards and function properly without interfering with or being impacted by other equipment. These tests generally include:

Emission Testing

- This test measures the electromagnetic emissions a device produces to make sure the emissions fall within acceptable limits (Compliance Testing)

Immunity Testing

- Evaluates how well a device can withstand external electromagnetic disturbances without degradation of performance (*Electromagnetic Compatibility (EMC) Testing*)

These tests are crucial for making sure the safety, reliability, and regulatory compliance of electronic devices in practical environments.

5 Test Description

During the tests, two TIDA-010261 PCBs were connected with either a shielded or an unshielded twisted pair of Single Pair Ethernet cable. The boards are powered by an external 24V power supply.

To test the data integrity during immunity tests, Linux is running from eMMC, one board is running an iperf3 server, the other one connects to the iperf3 server and runs a TCP throughput test for the run time of the immunity test. From the output of iperf3, the data rate and retry counter were monitored, from the hardware, the link LEDs were monitored

```
Connecting to host 192.168.1.11, port 5201
[  6] local 192.168.1.10 port 43962 connected to 192.168.1.11 port 5201
[ ID] Interval           Transfer     Bitrate         Retr  Cwnd
[  6]   0.00-1.00   sec  1.24 MBytes  10.4 Mbits/sec    0   33.9 KBytes
[  6]   1.00-2.00   sec  1.14 MBytes  9.56 Mbits/sec    0   33.9 KBytes
[  6]   2.00-3.00   sec  1.14 MBytes  9.56 Mbits/sec    0   33.9 KBytes
[  6]   3.00-4.00   sec  1.14 MBytes  9.56 Mbits/sec    0   33.9 KBytes
[  6]   4.00-5.00   sec  1.14 MBytes  9.56 Mbits/sec    0   33.9 KBytes
```

Figure 5-1. Iperf3 EFT Data Recording Begins

```
[  6] 595.00-596.00 sec  1.24 MBytes  10.4 Mbits/sec    6   21.2 KBytes
[  6] 596.00-597.00 sec  1018 KBytes  8.34 Mbits/sec    5   24.0 KBytes
[  6] 597.00-598.00 sec  1.24 MBytes  10.4 Mbits/sec    5   28.3 KBytes
[  6] 598.00-599.00 sec  1018 KBytes  8.34 Mbits/sec    6   21.2 KBytes
[  6] 599.00-600.00 sec  1.24 MBytes  10.4 Mbits/sec    4   24.0 KBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Retr
[  6]   0.00-600.00 sec   657 MBytes  9.19 Mbits/sec  10835             sender
[  6]   0.00-600.01 sec   657 MBytes  9.18 Mbits/sec                  receiver

iperf Done.
```

Figure 5-2. Iperf3 EFT Data Recording End

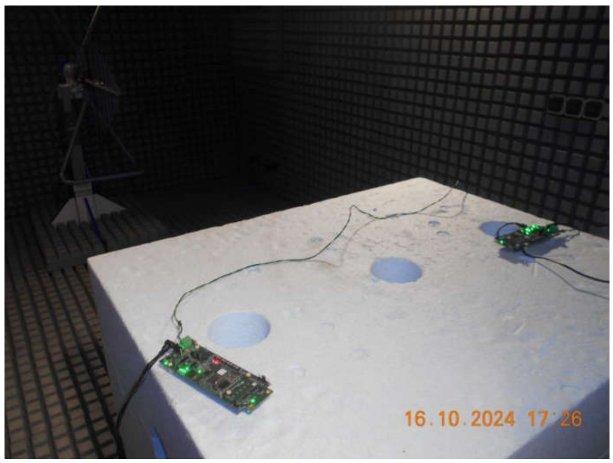

Figure 5-3. Two Connected TIDA-010261 With Single Pair Ethernet

6 Test Details and Results

6.1 Burst: IEC 61000-4-4

Is a standard that specifies the requirements and methods for testing the immunity of electrical and electronic equipment to electrical fast transients (EFT), commonly known as *bursts*. These bursts are short, rapid, high-frequency pulses that simulates switching transients typically generated by inductive loads, relay contact switching, or other rapid changes in power circuits. The purpose of this standards is to make sure that devices can continue to function properly without data loss or hardware failure when exposed to these types of disturbances.

The testing setup includes a burst generator capable of producing pulses with specified voltage levels, pulse duration, and repetition rates. The pulse are coupled to the EUT through either direct injection into power lines or capacitive coupling to signal and control lines using a Capacitive Coupling Clamp (CCC). This device is used to inject EFT/Burst disturbances into the EUT without a direct electrical connection. The standard burst test set-up includes levels in kV from 0.5kV to several kV and a frequency use of 5kHz or 100kHz, depending on the severity class being tested. The coupling and decoupling network (CDN) is an essential part of the test setup, making sure that the burst energy is properly applied without interfering with unrelated parts of the circuit. The EUT is tested for the response while operational and monitored for any sings of malfunction, disruption, damage. The evaluation criteria include determine whether the equipment experiences a temporary performance drop, loss of data or complete failure (*EMC Standards*).

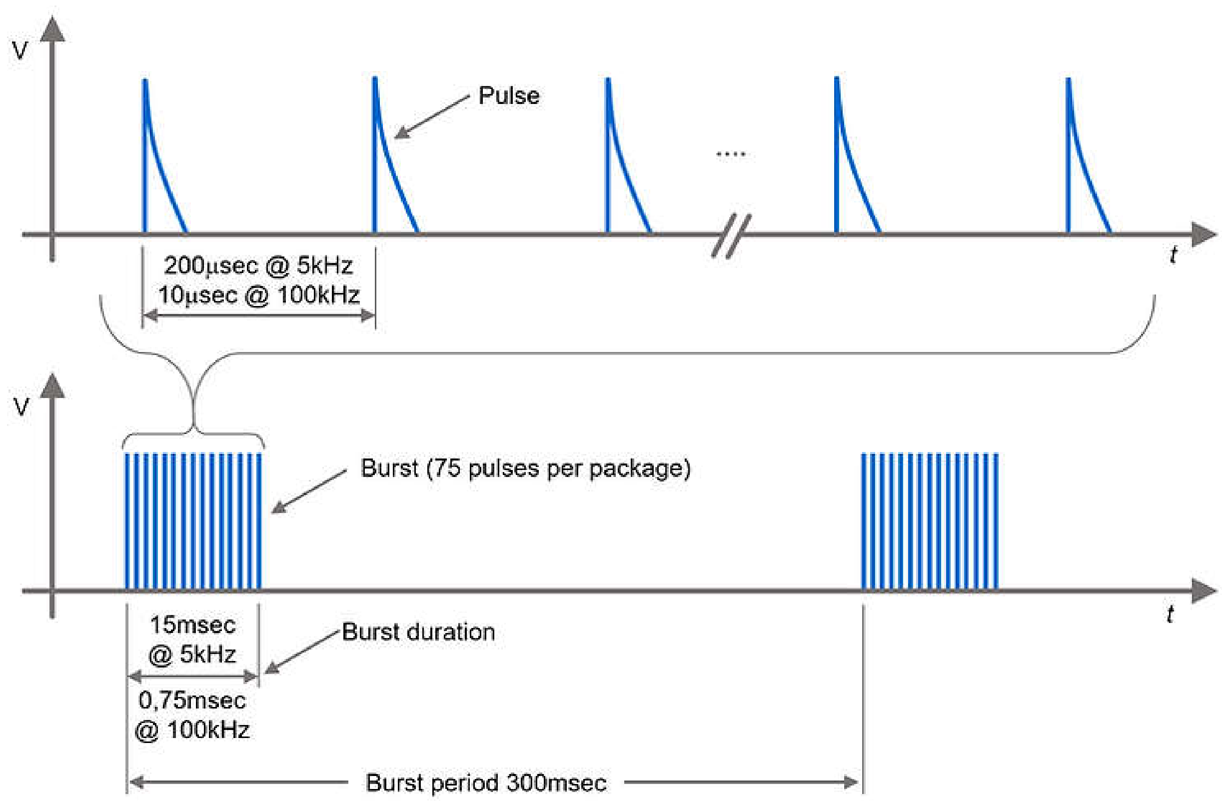

Figure 6-1. Burst 61000-4-4 Generator Output Signal

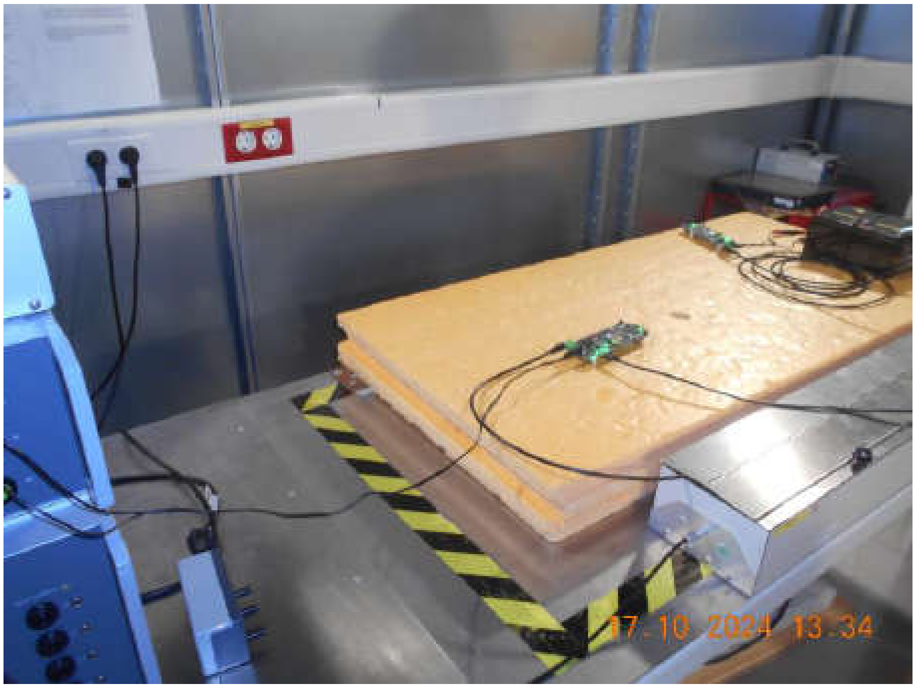

Figure 6-2. TIDA-0101261 in Burst Test Setup

Table 6-1. TIDA-010261 EFT Results

Test	IEC Standard	Cable	Test Signal		Test Description	Criterion	Test Result
			Voltage	Frequency			
EFT	IEC 61000-4-4	shielded SPE	±2kV	5kHz	Burst on DC-in CDN coupled	A	pass
				100kHz		A	pass
	IEC 61000-4-4	shielded SPE	±2kV	5kHz	Bust on SPE CCC coupled	A	pass
				100kHz		A	pass

Table 6-1. TIDA-010261 EFT Results (continued)

Test	IEC Standard	Cable	Test Signal		Test Description	Criterion	Test Result
			Voltage	Frequency			
EFT	IEC 61000-4-4	unshielded twisted-pair	±2kV	5kHz	Burst on DC in	B*	pass
				100kHz		B*	pass
	IEC 61000-4-4	unshielded twisted-pair	±2kV	5kHz	Burst on SPE CCC coupled	B*	pass
				100kHz		B*	pass

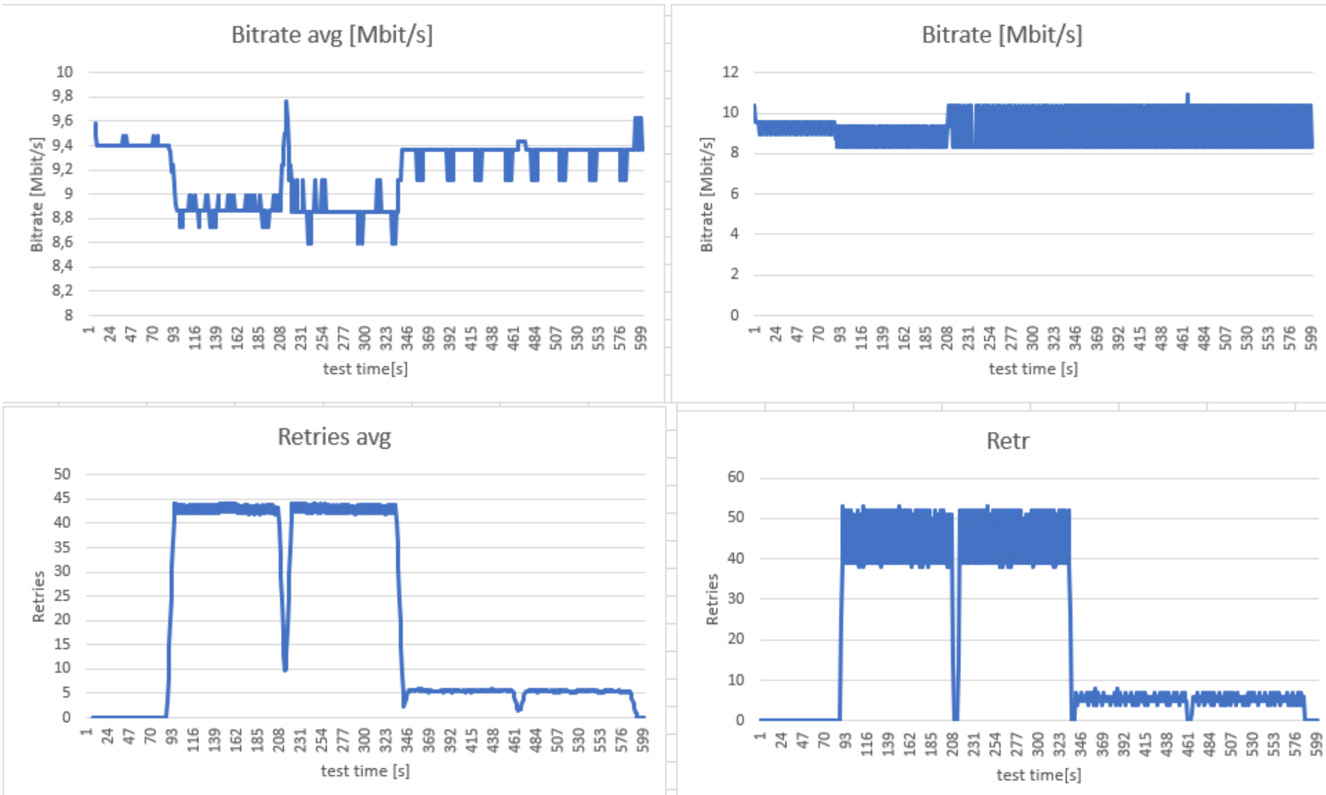

Figure 6-3. Iperf 3 Result Plot Shielded Cable

6.2 ESD: IEC 61000-4-2

Electro Static Discharge is a technical standard that provides a framework for testing the immunity of electrical and electronic equipment against electrostatic discharges (ESD).

This standard specifies the requirements for both test setups and procedures, making sure of consistent and repeatable testing to evaluate how a device responds to ESD events.

Technically, the standards cover two main types of discharge: contact discharge and air discharge. Contact discharge involves directly applying, the electrostatic charge through a conductive tip to the device under test (DUT, which provides more controlled and repeatable results. Air discharge simulates the scenario where the electrostatic energy jumps through the air to the DUT, representing real-world situations where contact can not be exactly conductive.

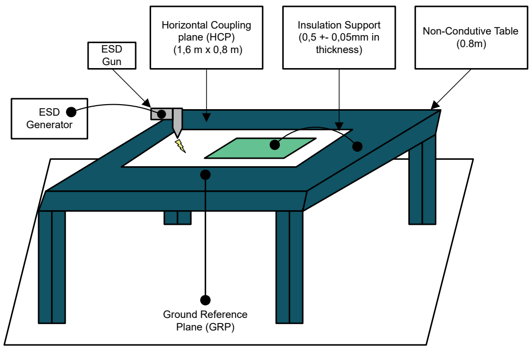

Figure 6-4. Example of Basic ESD Set-up of Test Bench

The standard defines several levels of test voltage, usually measured in kilovolts (kV). From low (2kV) to high (15kV or more). Key aspect of IEC 61000-4-2 includes the use of an ESD simulator (ESD gun) cable of delivering precise voltage pulses, and specifications for verification of the discharge waveform to make sure this meets strict timing and amplitude criteria. The purpose of this testing standard is to make sure that devices can withstand static discharges that can occur during handling, operation, or environmental changes without suffering malfunction or breakdown.

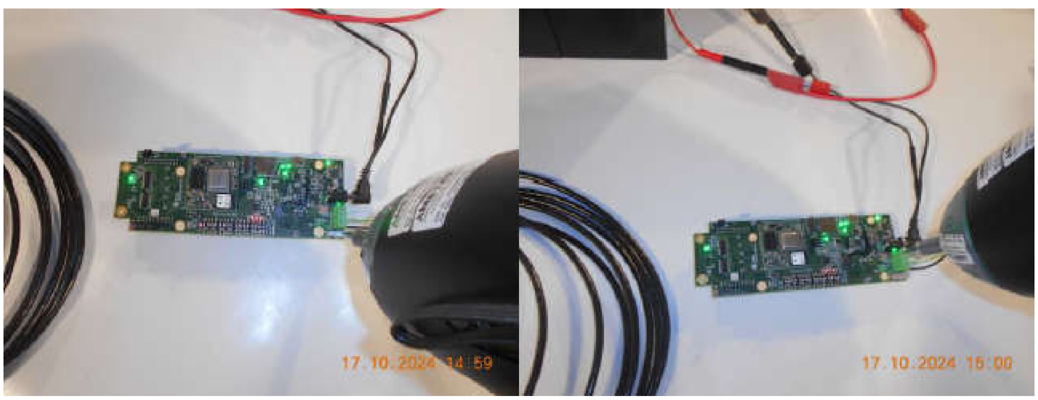

Figure 6-5. ESD Injection on TIDA-010261

For the ESD test, the EUT is tested with at least 20 discharges at each rating, 10 discharges each at a positive and negative polarity. Table 6-2 shows the results of the ESD tests.

Table 6-2. ESD Test Results TIDA-010261

Test	IEC Standard	Cable	Test Signal		Voltage Level/ Polarity	No of Injections	Result
			Injection Position	Modus			
ESD	IEC 61000-4-2	Shielded SPE	HCP/VCP	CD	.± 8kV	10 each	Pass crit. A
			SPE shield	CD	.± 8kV	10 each	Pass crit. B*
ESD	IEC 61000-4-2	Unshielded twisted pair	HCP/VCP	CD	.± 8kV	10 each	Pass crit. A
			SPE shield	CD	.± 8kV	10 each	Pass crit. B*
			Twisted pair terminal	CD	.± 4kV	10 each	Pass crit. B*

6.3 Surge: IEC 61000-4-5

Is a standard that sets the guidelines for testing the immunity of electrical and electronic equipment to surge voltages, which are high-energy transient resulting from events such as lightning strikes and power switching. These surges can cause significant damage to electronic systems and components, making this crucial for devices to be designed to handle such occurrences without failure. Surge testing involves the use of a surge generator capable of producing defined waveform characteristics, typically an 1.2/50µs voltage waveform or an 8/20µs current waveform. These parameters specify the rise time and duration of the surge pulse.

The connection between the EUT and the surge generator through coupling and decoupling network (CND) which help direct the surge to the intended points, such as power lines, signal lines or communication ports. The surge can be applied in both differential mode (between lines) and common mode (between lines and ground) to simulate real-world scenarios. The standard test levels, typically ranging from 0.5kV to several kilo volts with a high current, depending on the severity of testing. In this case the maximum ratings are 1kV and 24A current. The goal of these tests is to evaluate whether the EUT can withstand surge events without damage, data loss, or malfunction under specified conditions (*EMC Standards*).

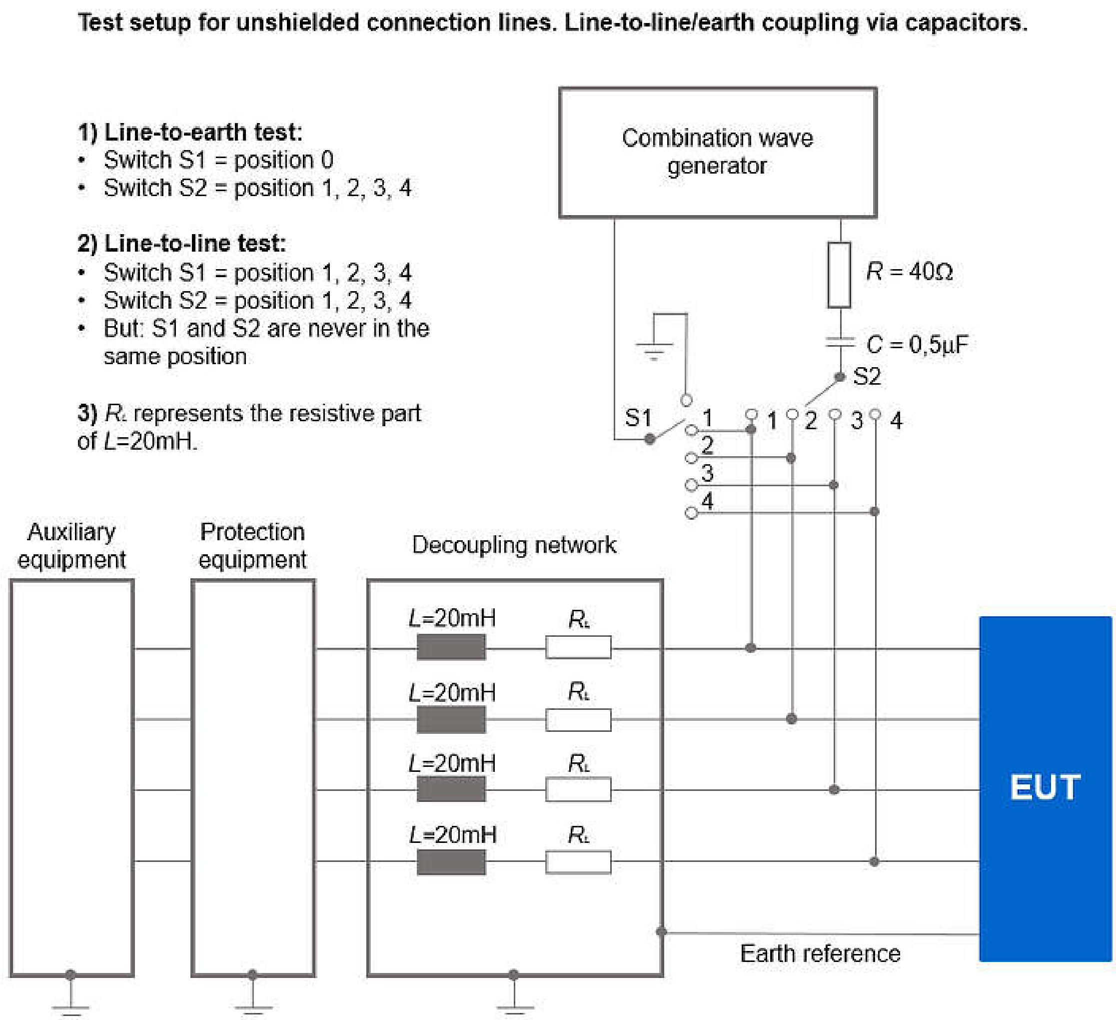

Figure 6-6. Decoupling Network Surge

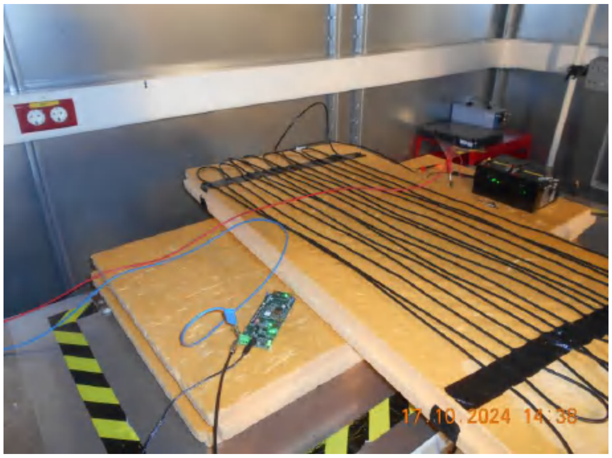

Figure 6-7. Surge Test Setup

Figure 6-8. Surge Test Setup

Table 6-3. Surge Test Results TIDA-010261

Test	IEC Standard	Cable	Impedance	Test Voltage	Test Description	Criterion	Test Result
Surge	IEC 61000-4-5	shielded SPE	41Ω (2Ω source impedance + 40Ω from coupling network)	500V	Surge on unshielded twisted pair	B	pass
	IEC 61000-4-5	shielded SPE	42Ω (2Ω source impedance + 40Ω from coupling network)		Surge on shielded cable direct injection	B	pass
Surge	IEC 61000-4-5	unshielded twisted-pair	43Ω (2Ω source impedance + 40Ω from coupling network)	1kV	Surge on unshielded twisted pair	B	pass
	IEC 61000-4-5	unshielded twisted-pair	44Ω (2Ω source impedance + 40Ω from coupling network)		Surge on shielded cable direct injection	B	pass

6.4 Cond-EMS: IEC 61000-4-6

Is a standard that focus on the immunity of electrical and electronic equipment to conducted radio frequency (RF) disturbances in the frequency range 150kHz to 80MHz this frequency range is 80% amplitude modulated (AM) with a 1kHz sine wave. This standard is relevant for environments where equipment can be exposed to RF signals conducted along cables, such as power lines or communication wires, which can induce unwanted currents and affect device performance.

The standard defines methods to simulate real-world RF disturbances that can enter the equipment through these conductive paths. The standard specifies the use of RF generators and power amplifiers to create the disturbance signals, which are then injected into the EUT through coupling and decoupling networks or current injection probes. The coupling devices make sure that the RF energy is applied consistently to the relevant part of the PCB while decoupling devices isolate the test signals to prevent interference with other parts of the setup. The goal of the test is to evaluate how well the equipment can continue to function in the presence of RF disturbances without experiencing performance, data loss or operation failure.

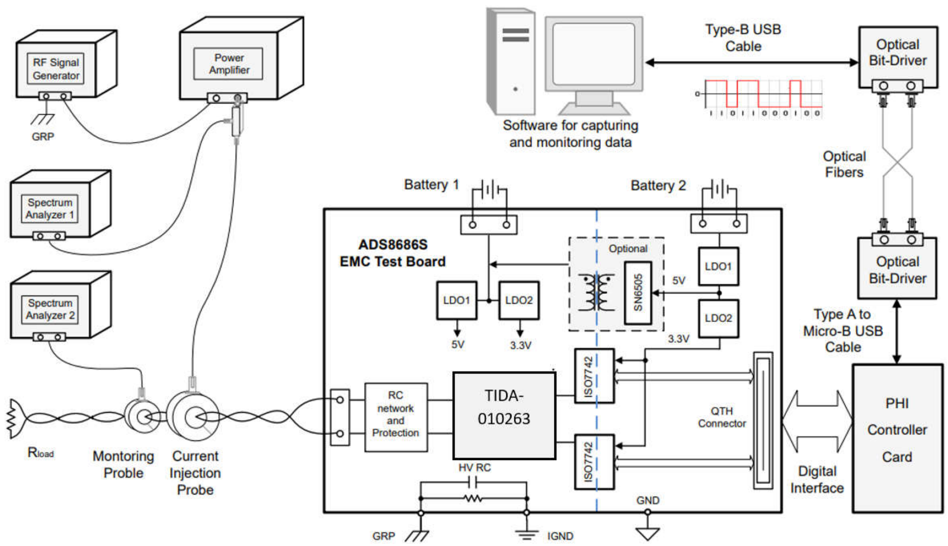

Figure 6-9. Block Diagram Cond-EMS Test Setup (Example)

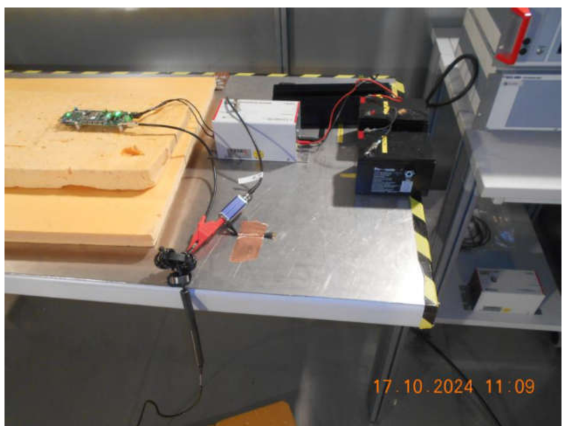

Figure 6-10. TIDA-010261 in Cond-EMS Test Setup

Table 6-4. Results Cond-EMS on TIDA-010261

Test	IEC Standard	Cable	Test Signal		Test Description	Criterion	Test Result
			Field Strength	Frequency			
Conducted Immunity	IEC 61000-4-6	shielded SPE cable	20V	150kHz-80MHz	Conducted immunity in DC input	A	pass
	IEC 61000-4-6	shielded SPE cable	20V	150kHz-80MHz	Conducted immunity on SPE	A	pass
Conducted Immunity	IEC 61000-4-6	unshielded twisted-pair	20V	150kHz-80MHz	Conducted immunity in DC input	A	pass
	IEC 61000-4-6	unshielded twisted-pair	20V	150kHz-80MHz	Conducted immunity on SPE	A	pass

6.5 Rad-EMS: IEC 61000-4-3

This is a technical standard that defines the procedures for testing the immunity of electrical and electronic equipment to radiated radio-frequency (RF) electromagnetic fields. This standard provides a detailed framework for evaluating how devices perform when exposed to continuous RF fields, simulating real-world conditions where equipment can face interference form radio transmitters, mobile phones, or other wireless communication devices.

Technically, the standard requires the use of an RF generator, amplifiers, and antennas capable of producing uniform fields over a defined frequency range, typically from 80MHz to 6GHz. This frequency range is 80% amplitude modulated (AM) with a 1kHz sine wave. The test setup must make sure a consistent electromagnetic field intensity, measured in volts per meter (V/m), across the area where the equipment under test (EUT) is placed. The standard specifies that the EUT needs to be tested in an anechoic chamber or a semi-anechoic chamber to minimize reflections and make sure accurate field application.

IEC 61000-4-3 outlines various test levels of field strength, with standard levels commonly ranging from 1V/m up to 10V/m or even higher for more stringent tests. The EUT is tested in multiple orientations to account for all possible angles of exposure to electromagnetic fields. During testing, the EUT needs to be monitored for any signs of performance degradation, data errors, or malfunctions.

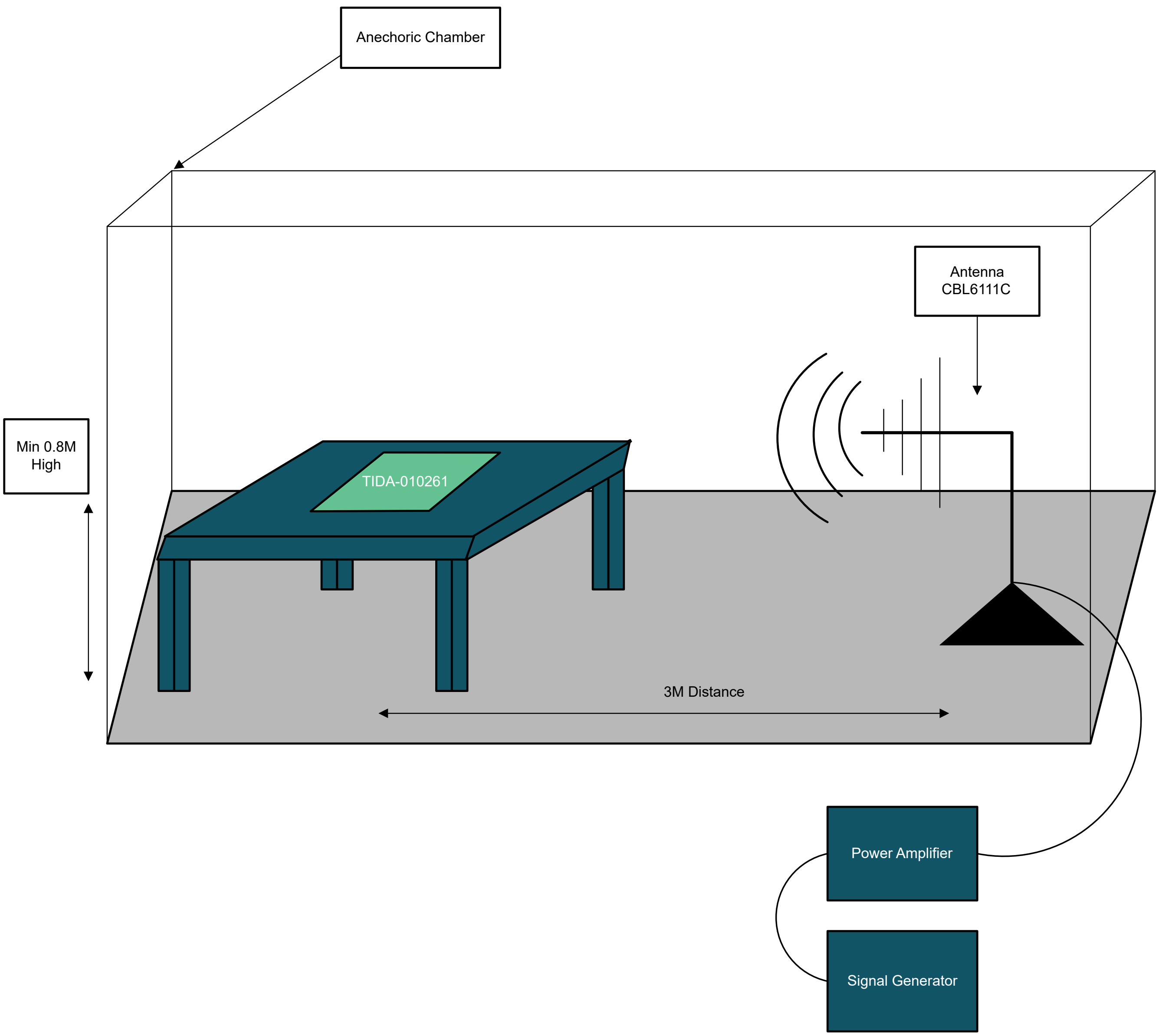

Figure 6-11. Radiated Immunity Test Set-up (Example)

Table 6-5. Radiated Immunity Test Result TIDA-010261

Test	IEC Standard	Cable	Test Signal		Antenna Polarization	Criterion	Test Result
			Field Strength V/m	Frequency			
Radiated Immunity (RI)	IEC 61000-4-3	shielded SPE cable	20V/m	80 MHz-1 GHz	Horizontal	A	pass
					Vertical	A	pass
	IEC 61000-4-3	shielded SPE cable	10V/m	1GHz-6GHz	Horizontal	A	pass
					Vertical	A	pass
Radiated Immunity (RI)	IEC 61000-4-2	unshielded twisted-pair	20V/m	80MHz-1 GHz	Horizontal	A	pass
					Vertical	A	pass
	IEC 61000-4-3	unshielded twisted-pair	10V/m	1GHz-6 GHz	Horizontal	A	pass
					Vertical	A	pass

6.6 Cond-EMS EN 61000-6-3 EMCL DC (LISN)

This standard defines the requirements for controlling electromagnetic emissions from devices used in residential, office and light industrial environments. The standard makes sure that electronic equipment does not emit excessive electromagnetic disturbances that can interfere with the frequency range of 0.15MHz to 30MHz.

To verify compliance, testing procedures are defined for both types of emissions. Conducted emissions are measured using Line Impedance Stabilization Networks (LISN), while radiated emissions are assessed with antennas and spectrum analyzers, typically in semi-anechoic chambers or open-area test sites. The EUT must be configured in the typical operating state, including all connected cables and peripherals, as this can influence emissions. For this reason, the conducted emissions on DC input were measured.

Global Graph:

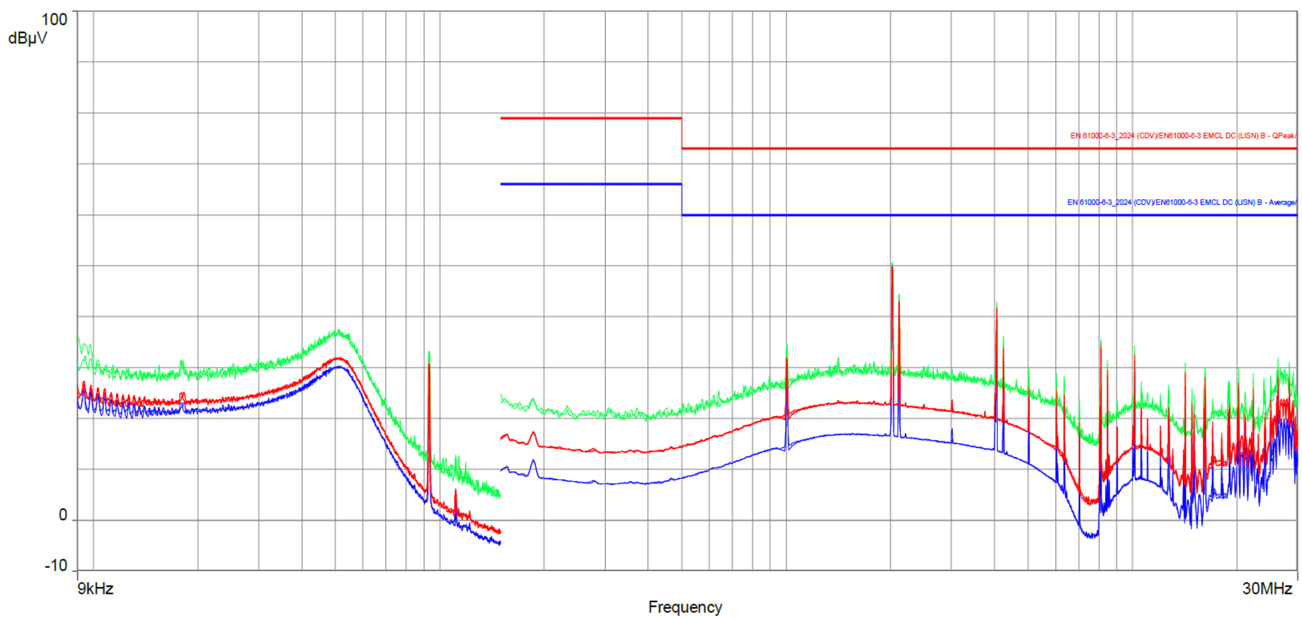

Figure 6-12. Global Graph Shielded SPE Cond-EMS EN 61000-6-3 EMCL DC (LISN)

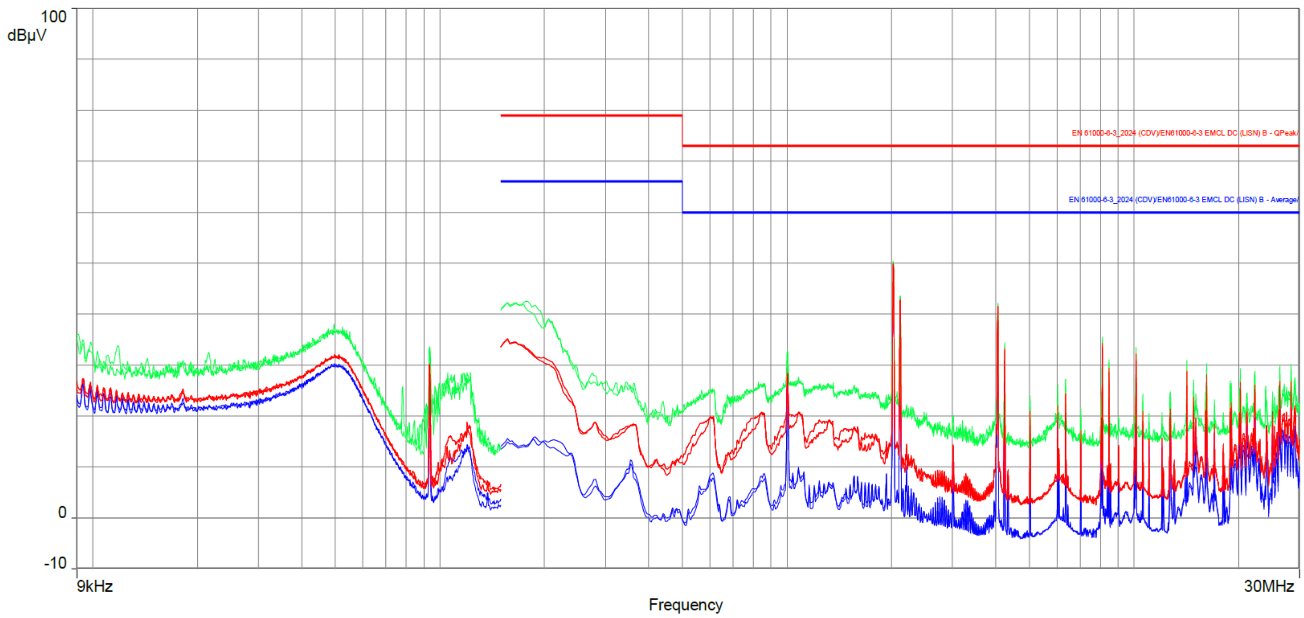

Figure 6-13. Global Graph Unshielded Twisted Pair Cond-EMS EN 61000-6-3 EMCL DC (LISN)

6.7 CISPR 32

This is an international standard that specifies the limit and measurement methods for electromagnetic emissions from multimedia equipment. This includes devices that perform various functions such as information technology, audio, video and broadcast reception. The primary objective of CISPR 32 is to make sure that multimedia equipment does not emit electromagnetic interference (EMI) levels that can disrupt the operation of nearby devices and systems. CISPR 32 defines both conductive and radiated emission limits. Conducted emissions refer to unwanted RF signals that travel along power or signal cables, while radiated emissions pertain to electromagnetic energy radiated directly into the air by equipment.

Testing for compliance involves placing the PCB in a controlled environment, such as an anechoic or semi.-anechoic chamber, and measuring emissions using a standardized test equipment, including antennas, spectrum analyzers [GS1] , and Line Impedance Stabilization Networks. These setups help make sure that emission levels remain below specified limits and do not interfere with other devices.

Actually, special receivers are used, more sensitive, different filters, different detectors. But nowadays some spectrum analyzers have this integrated.

6.8 Cond-EMS CISPR 32 Signal

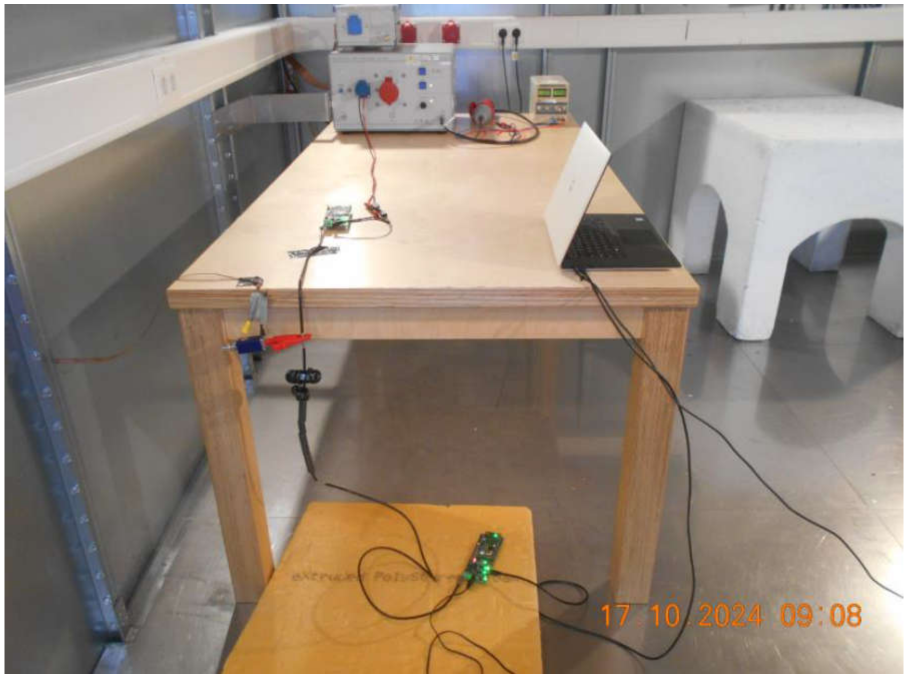

Figure 6-14. Conducted Emissions CISPR 32 TIDA-010261

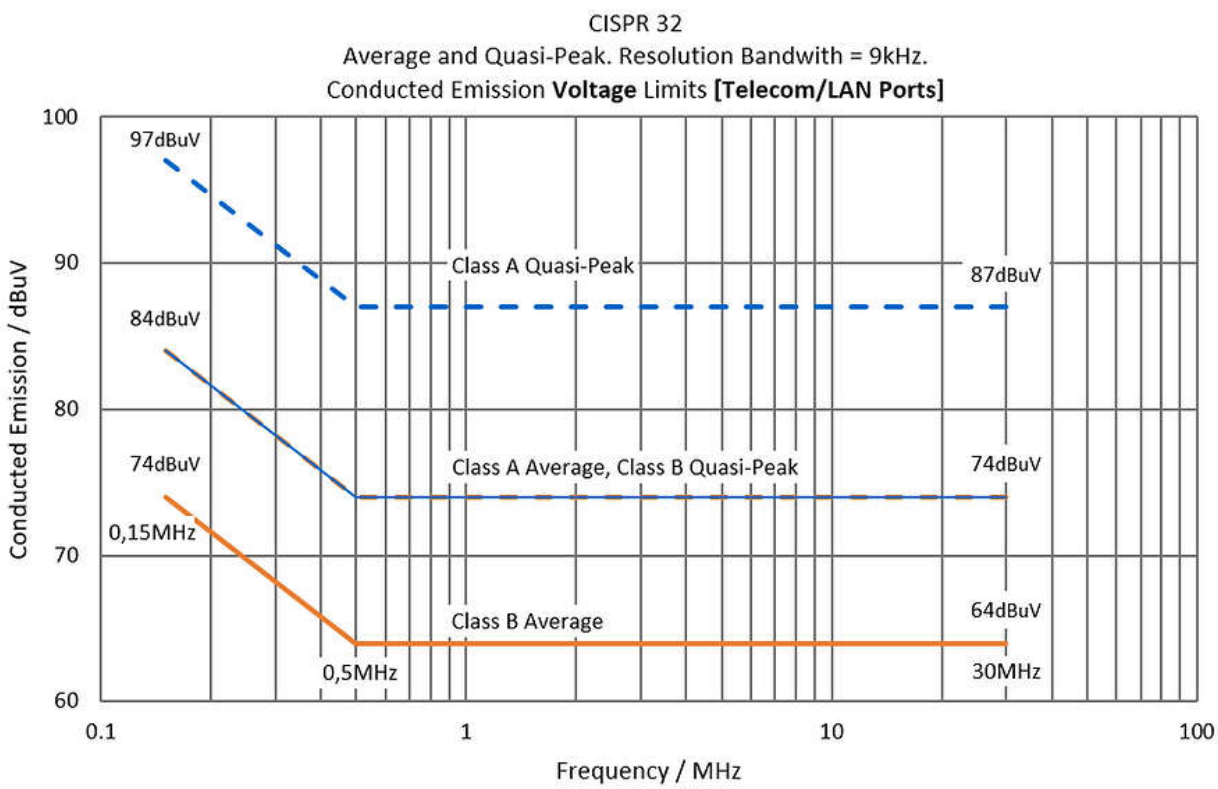

Figure 6-15. Conducted Emissions CISPR 32 Signal Limits

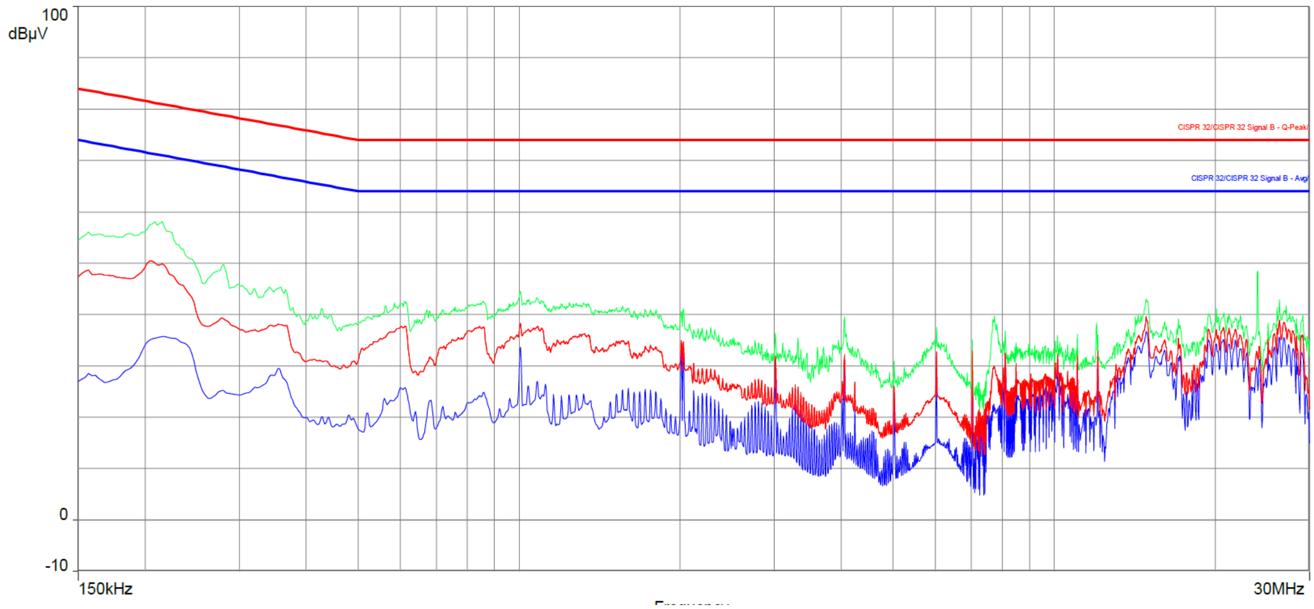

Figure 6-16. Conducted Emissions CISPR 32 Signal Shielded SPE Cable

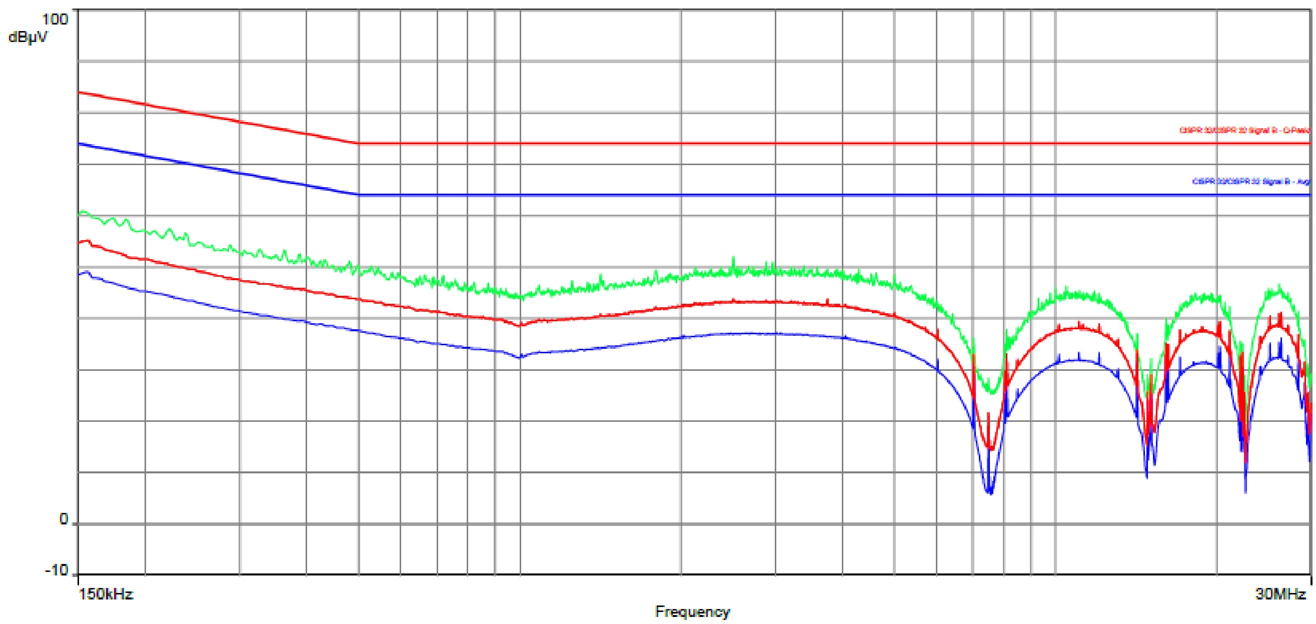

Figure 6-17. Conducted Emissions CISPR 32 Signal Unshielded Twisted Pair

6.9 Rad EMS CISPR 32 FAR

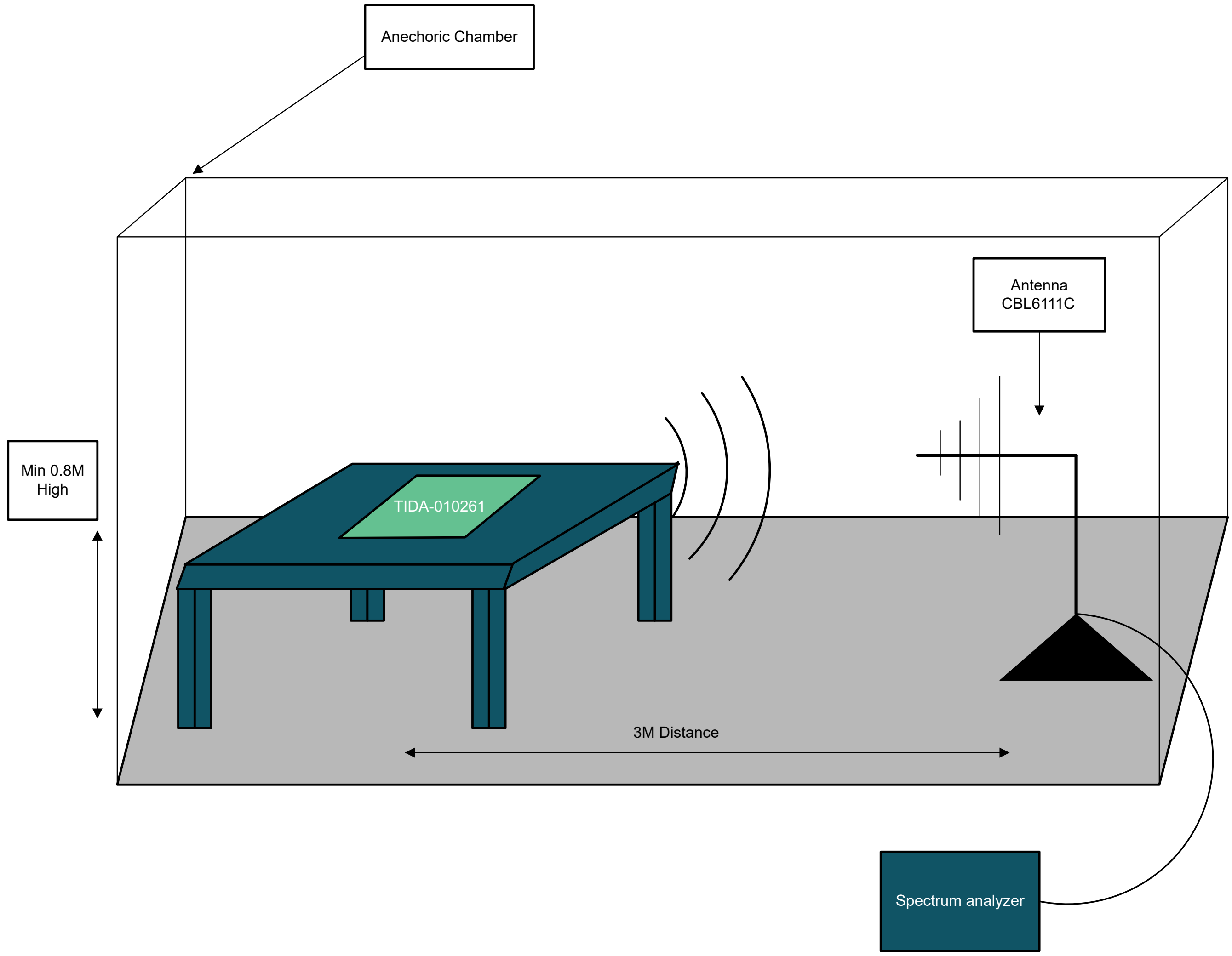

Figure 6-18. CISPR 32 FAR Test Set-up (Example)

Figure 6-19 plots the relevant limit lines for Class A and Class B at 3m and 10m distance between the antenna and EUT when using a QP detector (*EMC Standards*).

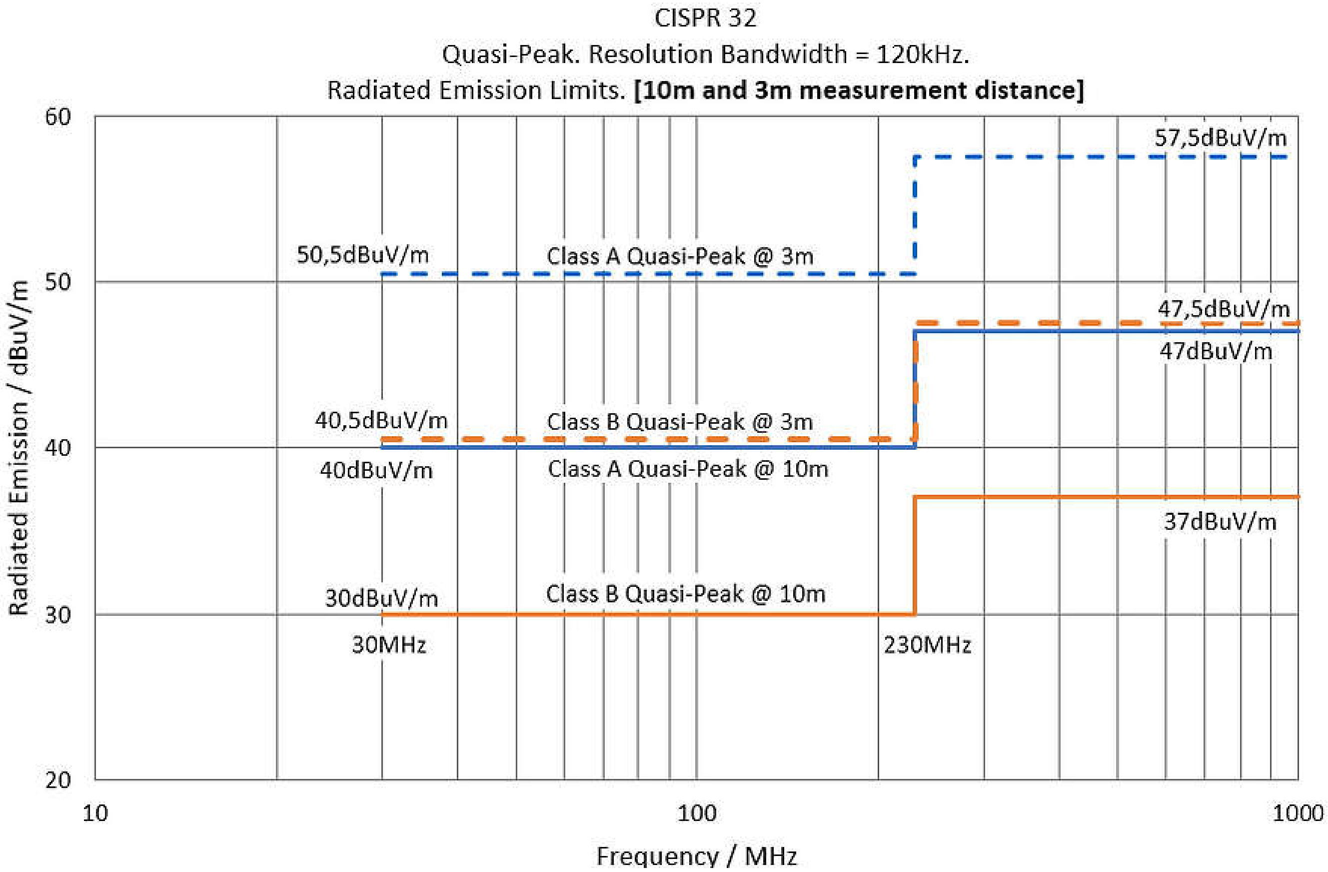

Figure 6-19. Radiated Emissions CISPR 32 Limits

Table 6-6. CISPR 32 FAR Test Result TIDA-010261

IEC Standard	Cable	Frequency Range (MHz)	3m Distance	
			Class A (dBµV/m)	Class B (dBµV/m)
CISPR 32	shielded SPE cable and unshielded twisted pair	150kHZ - 30MHz	43	30
		30MHz - 230MHz	50.5	40.5
		230MHz - 1GHz	57.5	47.5
		1GHz - 3GHz	76	70
		3GHz - 6GHz	80	74

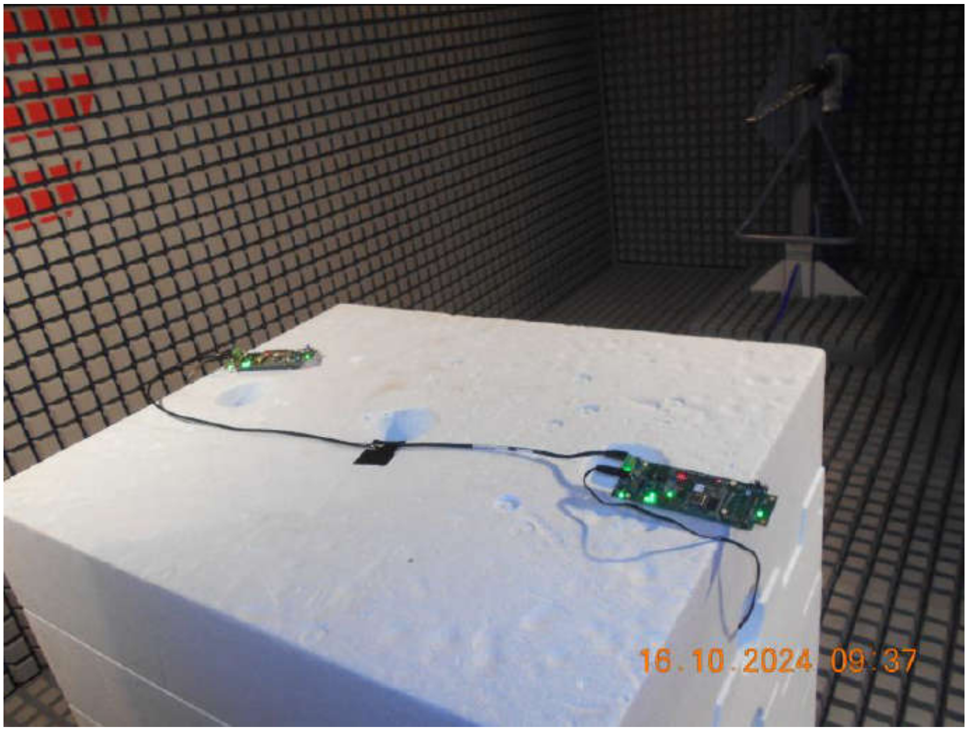

Figure 6-20. Test Set-up TIDA-010261 Shielded SPE Radiated Emissions

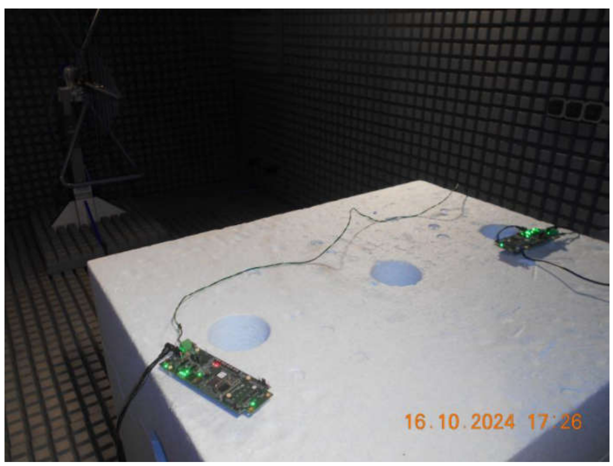

Figure 6-21. Test Set-up TIDA-010261 Unshielded Single Twisted Pair Radiated Emissions

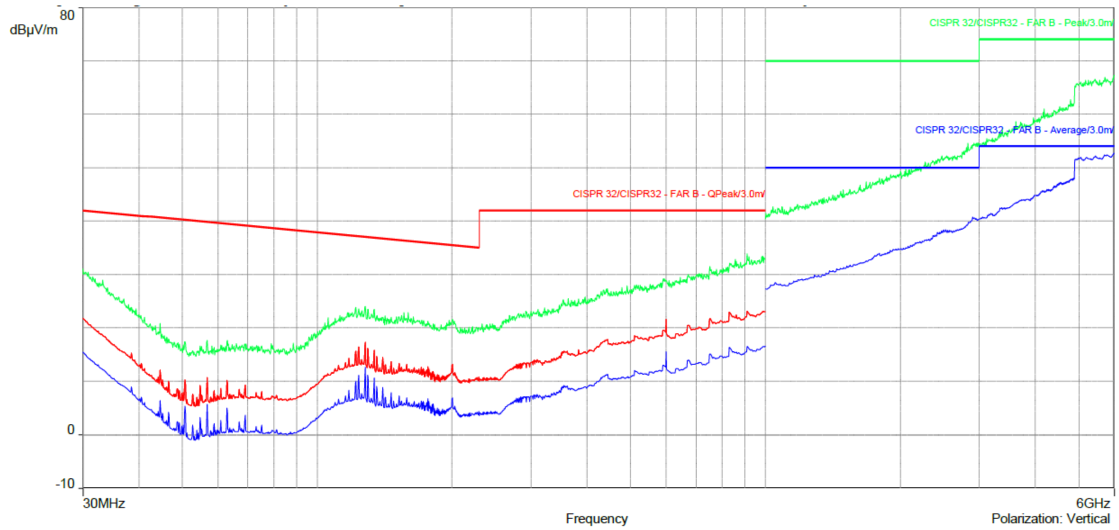

Figure 6-22. CISPR 32 FAR Signal, Radiated Emissions Shielded Cable, Vertical

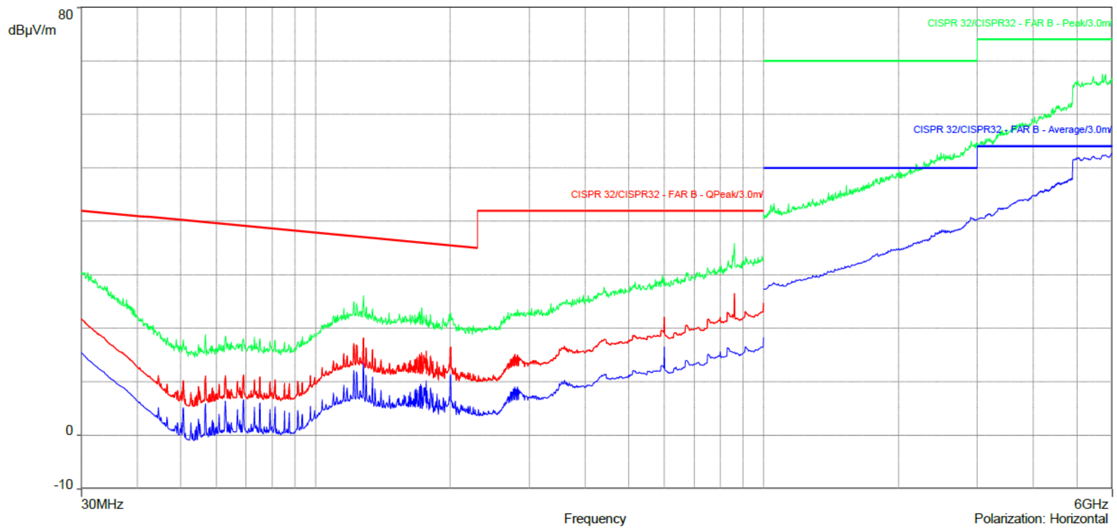

Figure 6-23. CISPR 32 FAR Signal, Radiated Emissions Shielded Cable, Horizontal

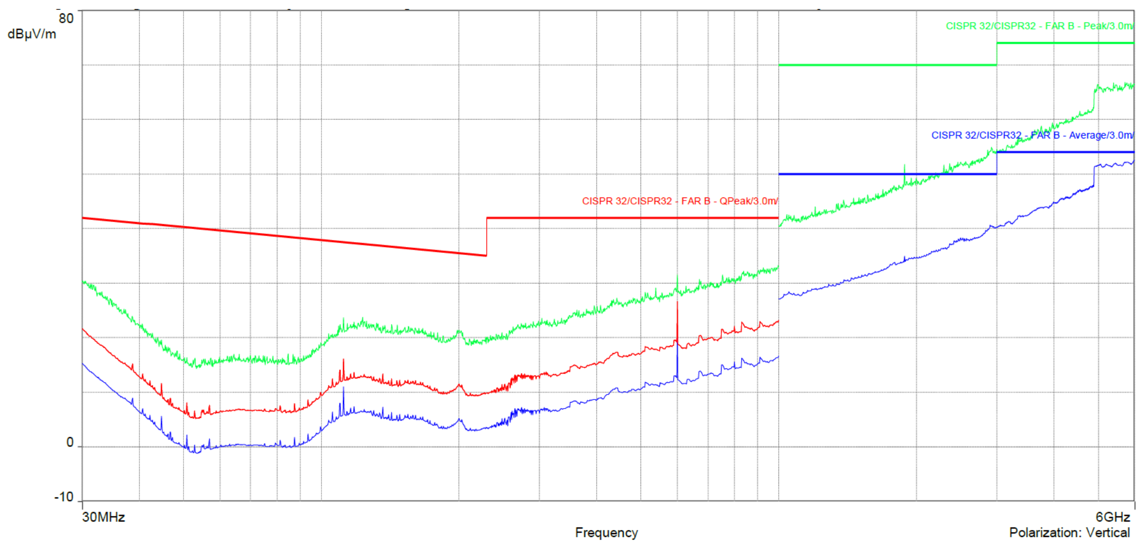

Figure 6-24. CISPR 32 FAR Unshielded Cable, Vertical

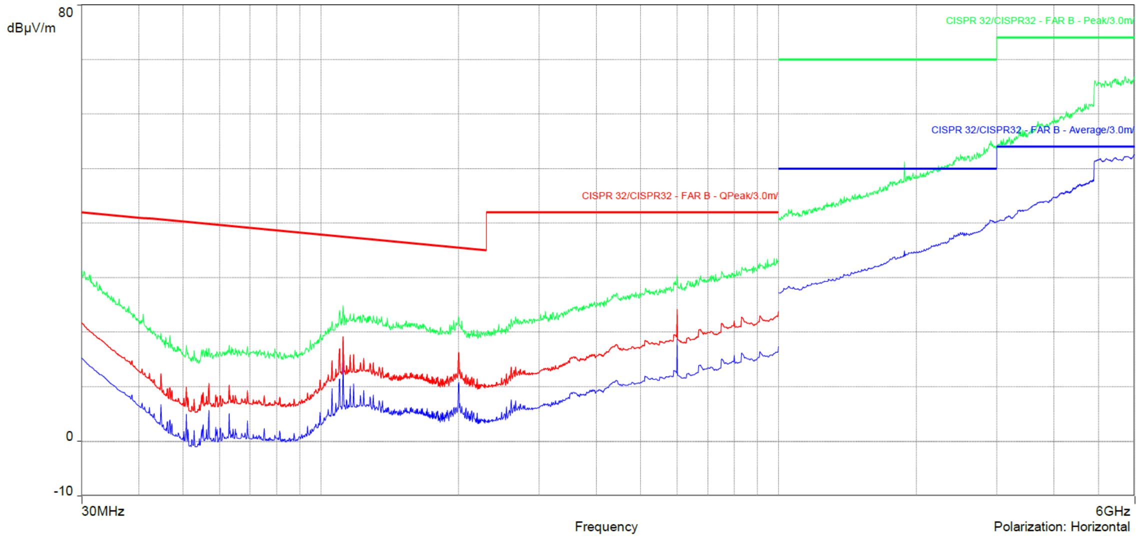

Figure 6-25. CISPR 32 FAR Unshielded Cable, Horizontal

7 Summary

All tests have been passed satisfactorily and the EMI/EMC capability of the TIDA-010261 has been demonstrated and tested.

There is potential for further improvement. For example SD-Cards operate at a clock frequency of 200MHz with a rise time of 1ns. To reduce these emissions, there is a possibility to use the internal EMMC. To mitigate the EMI behavior, matching the trace length an impedance in the design is crucial.

8 References

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7. IEC System of Conformity Assessment, *Standard IEC 61000-4-3:2020*.
8. Ametek Compliance Test Solutions, *IEC 61000-4-4 EFT/Burst*.
9. EMC Standards, *Handbook on EN 6100-4-4: Electrical fast transients and the EN 61000-4-4 test method*.
10. Academy of EMC, *EMC Standards*.
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