Application Note

CISPR 25 HV/LV COUPLING ATTENUATION MEASUREMENTS WITH R&S® ELEKTRA

Products:

- R&S®ELEKTRA

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https://www.rohde-schwarz.com/product/elektra

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Contents

1 Overview

Electric (EV) and hybrid electric (HEV) vehicles have both high-voltage (HV) and low-voltage (LV) electric systems. The LV systems are typically unshielded (infotainment, lighting, sensors etc.) and HV systems (battery packs, inverters, electric motors etc.) are shielded. The HV systems ranges from 400 V to 1500 V and the LV system ranges from 12 V to 48 V. The switching operations in HV systems can generate significant electromagnetic noise that may couple into the LV system and degrade performance or cause malfunctions.

The HV/LV coupling tests in line with CISPR 25

– Defines the test setup where HV systems are modified to inject disturbance at specific levels for different classes of equipment under test (EUT).
– Defines test methods for measuring the coupling attenuation between HV and LV systems.
– Defines test methods to measure conducted emissions (current and voltage) on LV systems during HV system operation.
– Defines test method to measure radiated noise (electric field) emissions when operating HV systems.

The HV/LV coupling tests are emission tests in line with CISPR 25 but some require an immunity test setup to inject disturbance into the system. This application note describes how to set up R&S®ELEKTRA and perform HV/LV coupling attenuation measurements.

2 Scope

This application note is based on Elektra v5.20. The application note explains the testing principles, how to configure the hardware and test templates to perform the coupling attenuation measurements in line with Annex I.5 of [1]

3 R&S® ELEKTRA licenses

The following R&S ELEKTRA licenses and options are required to perform HV/LV attenuation measurements.

– Required
  - EMS test software (Conducted) – ELEMS-C
– Optional
  - EMS system extension – ELEMS-S (for EUT specific test plan definition, automated testing & summary reports)

4 HV/LV coupling attenuation measurement

The HV system is shielded, which results in disturbance attenuations observed on the LV system.

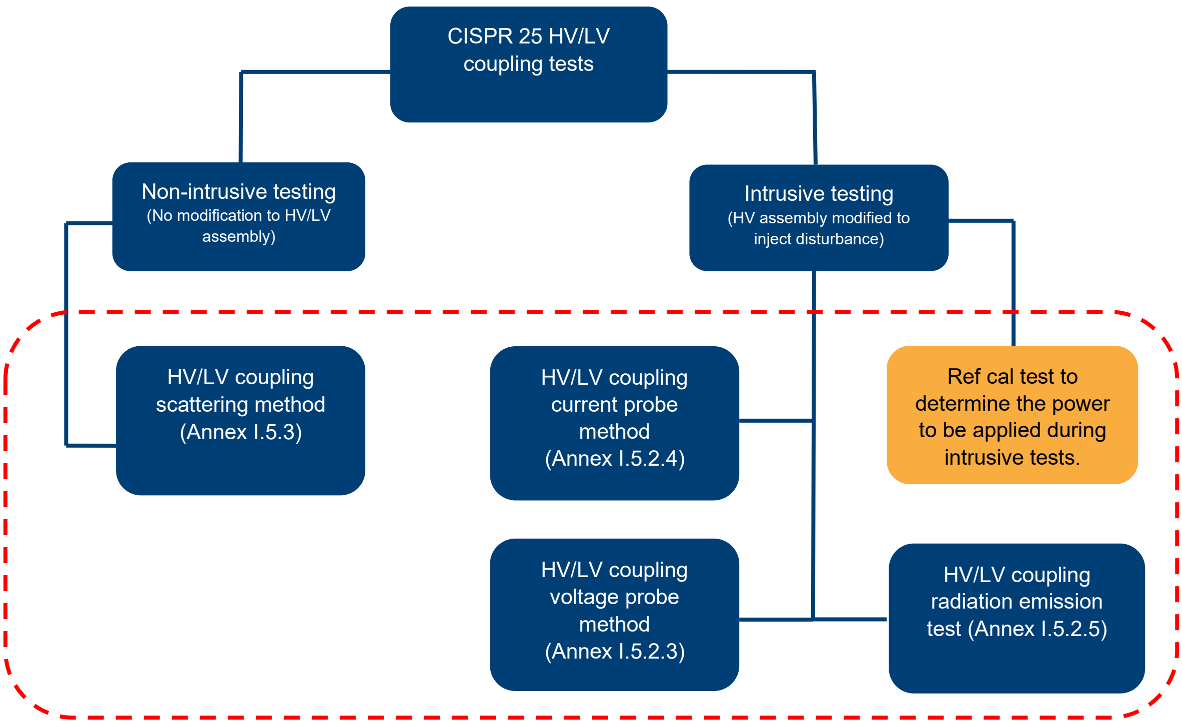


Figure 1: Overview of HV/LV coupling attenuation measurement tests.

Figure 1 gives an overview of tests that needs to be performed based on Annex I. During non-intrusive testing, no modifications are made to the HV and LV systems. In contrast, intrusive testing involves modifying the HV system to enable injection of a disturbance signal. Prior to conducting intrusive tests, a reference calibration test is needed to determine the appropriate injection power levels. Both the non-intrusive scattering method test and the intrusive reference calibration test are conducted with the equipment under test (EUT) in an unpowered state. Other tests have the EUT in a powered state.

As with the five CISPR 25 emission classifications (Class 1 to Class 5, Class 5 being the most stringent demanding least emission), CISPR 25 also introduces five HV/LV decoupling EUT attenuation classes. Figure 2 reproduces the minimum coupling attenuation requirements for different HV/LV EUT attenuation classes.

Table 1 shows the formulae for calculating the minimum attenuation requirements across frequencies for various EUT classes. As seen in Table 1, Class A1 is the most stringent demanding the maximum decoupling attenuation and Class A5 is the least stringent.

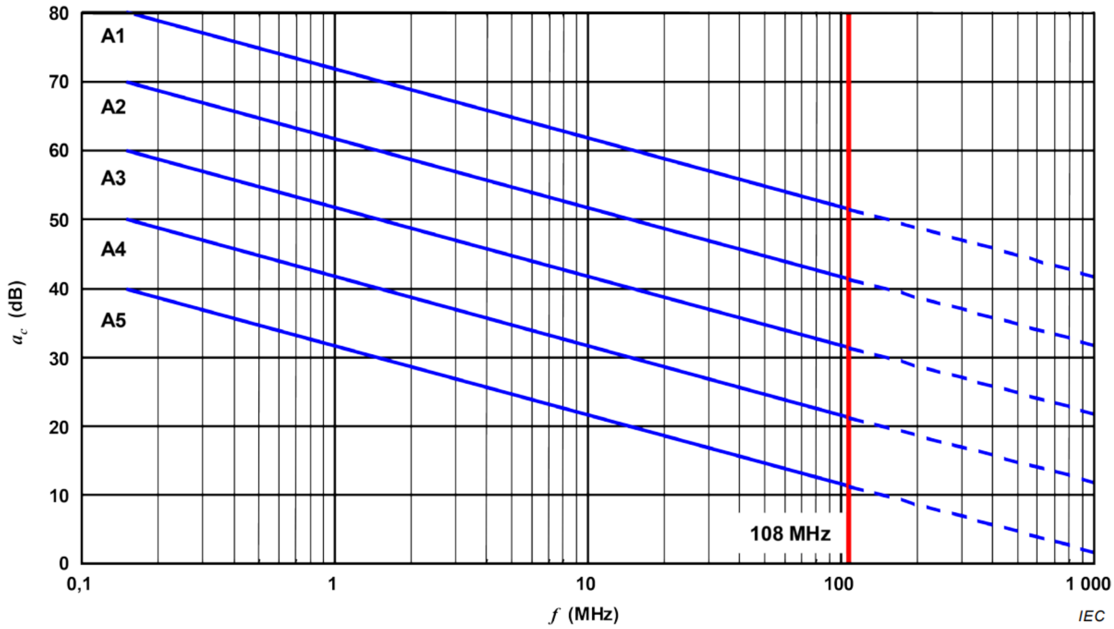


Figure 2: Minimum coupling attenuation requirements for different EUT classes, SOURCE: CISPR 25 [1]

Frequency (MHz)	Class	Min. Coupling Attenuation, a_c dB
0.15 to 1000	A1	$80 - 10 \times \log (f_{MHz} / 0.15)$
	A2	$70 - 10 \times \log (f_{MHz} / 0.15)$
	A3	$60 - 10 \times \log (f_{MHz} / 0.15)$
	A4	$50 - 10 \times \log (f_{MHz} / 0.15)$
	A5	$40 - 10 \times \log (f_{MHz} / 0.15)$

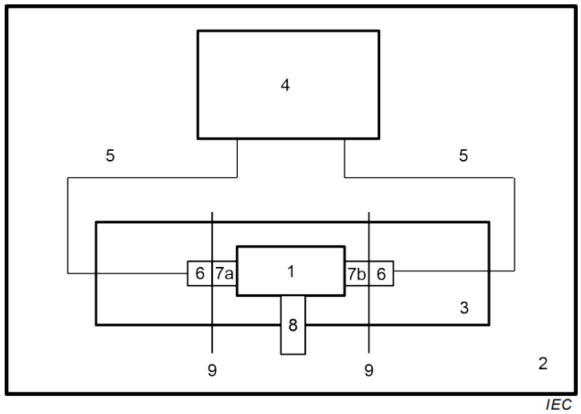
Table 1: Formula for calculating the minimum attenuation requirements, SOURCE: CISPR 25 [1]

4.1 Non-intrusive scattering method test

The coupling attenuation here (a_c) between HV/LV system is determined by directly measuring scattering parameters S_{21} with a vector network analyzer (VNA). No modifications are made to the HV and LV system side to perform the test. A complete two-port calibration of the VNA using the through-open-short-match (TOSM) method should be conducted prior to the scattering parameter measurement test. Users should consult Clause I.5.3 of [1] for full details.

The direct scattering method involves determining:

– Coupling attenuation (a_c) by relationship $a_c -= S_{21}$ based on S_{21} measurement.



Key

1 EUT
2 Ground plane
3 Low relative permittivity support ($\varepsilon_r \leq 1{,}4$) thickness 50 mm
4 Network analyser
5 High quality coaxial measuring cable e.g. double shielded (50 Ω)
6 Network analyser coaxial measuring cable connector
7a HV adaptor
7b LV adapter
8 EUT bonding connection
9 Reference plane for network analyser calibration

Figure 3: Typical direct scattering measurement setup for HV/LV coupling attenuation, SOURCE: CISPR 25 [1]

Figure 3 reproduces the setup for measuring the scattering parameters as illustrated in Clause I.5.3.4 of CISPR 25 [1].

	Port 1	Port 2
Configuration 1	Positive DC HV line	Positive LV line
Configuration 2	Negative DC HV line	Positive LV line
Configuration 3	Positive DC HV line	Negative LV line
Configuration 4	Negative DC HV line	Negative LV line

Table 2: Typical configurations for scattering measurements

Table 2 shows the typical S_{21} measurement configurations with positive and negative LV lines. If a negative LV line is not present, configurations with the negative line do not have to be included in the test plan.

The recommended VNA settings for the test as per clause I.5.3.2 in [1]

– Power level ≥ 0 dBm.
– Sweep type = LOG
– Sweep points ≥ 401.
– IFBW ≤ 1kHz
– Averaging factor ≥ 8

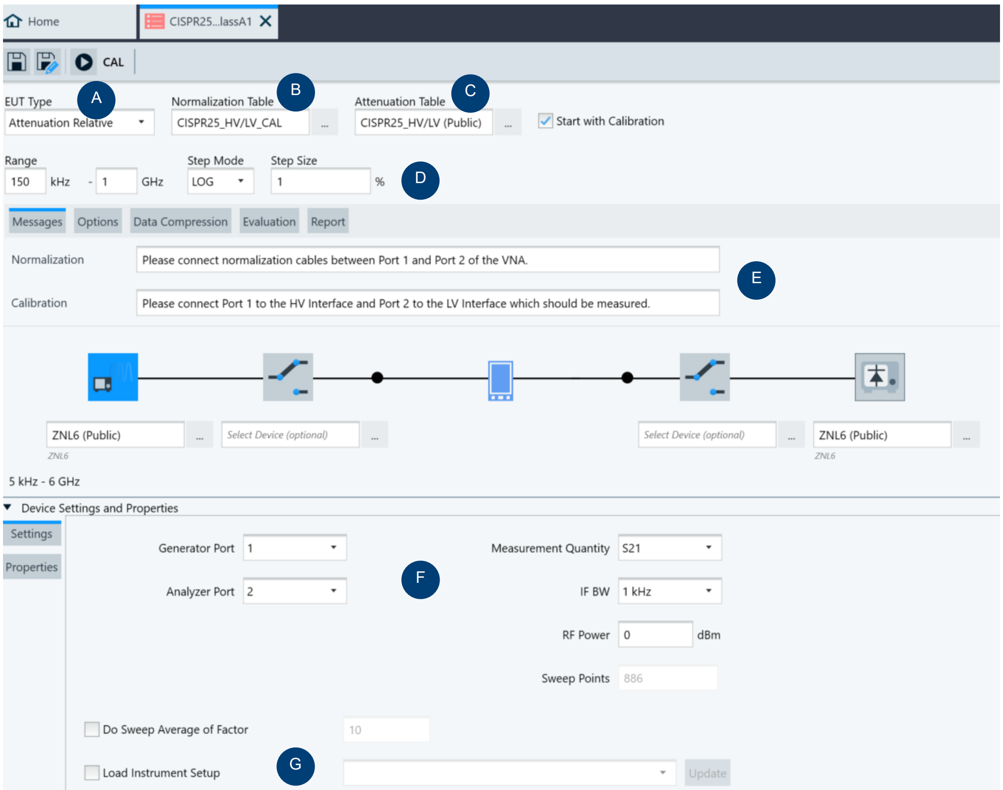
By understanding the details outlined above, customers can proceed with actual testing following the steps below.

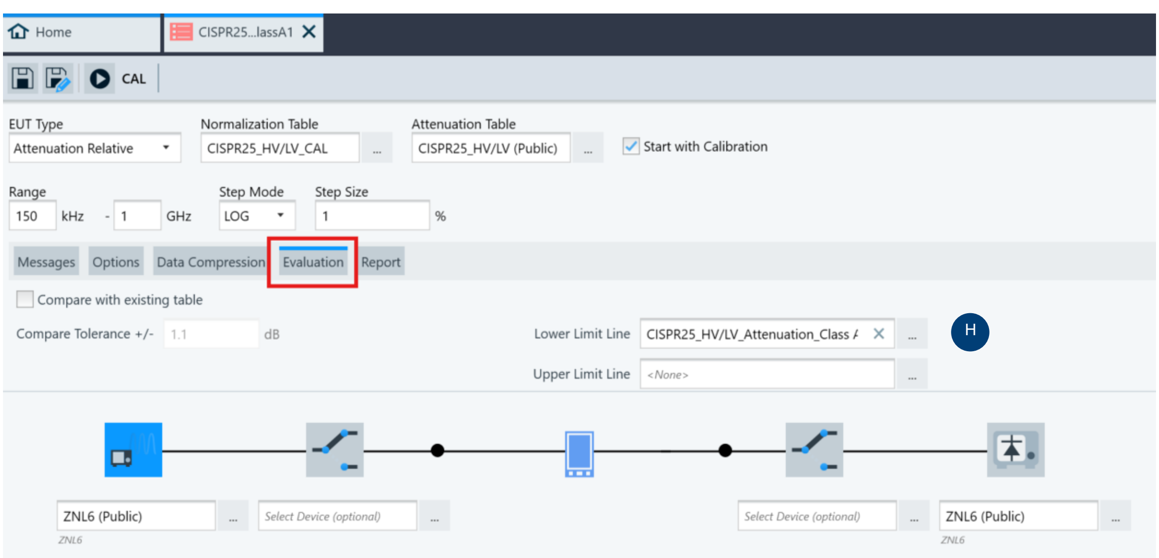
– Determine the EUT class.
– Create a limit line to define the minimum attenuation based on Table 1 for the identified EUT class.
– Determine the measurement configurations.
– Connect the EUT and VNA as per Figure 3, configure the VNA parameters and perform the test using R&S®ELEKTRA for each measurement configuration.

The calibration template in R&S®ELEKTRA is used to configure the settings for scattering parameter measurement method testing.

4.1.1.1 Coupling attenuation measurement template user interface previews

In this section, the UI to configure the various parameters described in section 4.1 are shown.





The various settings in the above screenshots are described below.

A. EUT Type = attenuation relative to determine the attenuation from S_{21} measurements
B. Normalization table shows reference measurements applied to correct the actual measurement data.
C. Attenuation table storing the coupling attenuation measurement results.
D. Frequency range, step mode and step size.
E. User feedback messages for connecting the test setup during measurement.
F. VNA settings as per clause I.5.3.2 in [1]
G. Since TOSM calibration is recommended, select load instrument setup to apply the chosen TOSM calibration file during testing. To retrieve all available TOSM files from the instrument, use the update function.
H. The limit line defining the minimum coupling attenuation required. This limit line is defined based on the EUT class as shown in Table 1

4.1.1.2 Coupling attenuation measurement test

The section describes the execution of tests and review of results.

- The coupling attenuation measurement test shown in Figure 4 is created by clicking “Create Test from Template” button in the template from 4.1.1.1. The normalization step may be skipped if the test setup remains unchanged since the last normalization measurement.

Figure 4: Coupling attenuation measurement test view.

- During test execution, the user must verify that the input and output ports are properly connected to the designated measurement points.

Figure 5: Coupling attenuation measurement test view after test execution.

- When the test is finished, the attenuation graph (coupling attenuation $a_C = -S_{21}$) in Figure 5 should have measurements above the specified limit line for all frequencies to pass.

4.2 Intrusive test methods

In intrusive tests, the HV side is modified to consecutively inject the disturbance signal into the system on both the HV+ and HV- ports. The LV side remains unchanged.

As a first step, a reference calibration test determines the required power levels for the disturbance signal injection. The disturbance signal levels are based on the CISPR 25 emission class and CISPR 25 coupling attenuation class.

4.2.1 Calibration procedure to establish input power levels for testing

Test levels are determined by adding the required coupling attenuation to existing LV emission limit lines with the formula: $U_{Limit,\,HV} = U_{Limit,\,LV} + a_C,\ A_x$, where $a_{C,\,Ax}$ represents the coupling attenuation for a specific class.

Figure 6 shows a portion of the HV limit class table for attenuation class A5 from Table I.1 in [1]. The values will be different for other attenuation classes and need to be determined. The basis for limit values seen in Figure 6 are derived from the Table limits 5 in [1]. Figure 7 shows a portion of the LV limit class table in Table 5 in [1].

Table I.1 – Example for HV limits for conducted voltage measurements at shielded power supply devices (HV-LV decoupling class A5)

Service / Band	Frequency MHz	Levels in dB(µV)														
		Class 5(A5)			Class 4(A5)			Class 3(A5)			Class 2(A5)			Class 1(A5)		
		Peak	Quasipeak	Average	Peak	Quasipeak	Average	Peak	Quasipeak	Average	Peak	Quasipeak	Average	Peak	Quasipeak	Average
BROADCAST																
LW	0,15 to 0,30	107	94	87	117	104	97	127	114	107	137	124	117	147	134	127
MW	0,53 to 1,8	84	71	64	92	79	72	100	87	80	108	95	88	116	103	96
SW	5,9 to 6,2	77	64	57	83	70	63	89	76	69	95	82	75	101	88	81
FM	76 to 108	50	37	30	56	43	36	62	49	42	68	55	48	74	61	54
TV Band I	41 to 88	47		37	53		43	59		49	65		55	71		61

Figure 6: HV limit class for attenuation class 5, SOURCE: CISPR 25 [1]

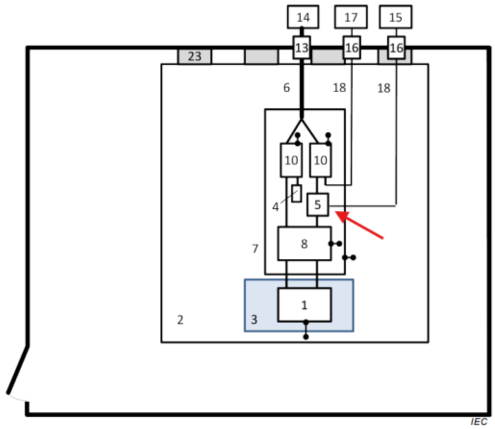
Table 5 – Examples of limits for conducted disturbances – Voltage method

Service / Band	Frequency MHz	Levels in dB(µV)														
		Class 5			Class 4			Class 3			Class 2			Class 1		
		Peak	Quasipeak	Average	Peak	Quasipeak	Average	Peak	Quasipeak	Average	Peak	Quasipeak	Average	Peak	Quasipeak	Average
BROADCAST																
LW	0,15 to 0,30	70	57	50	80	67	60	90	77	70	100	87	80	110	97	90
MW	0,53 to 1,8	54	41	34	62	49	42	70	57	50	78	65	58	86	73	66
SW	5,9 to 6,2	53	40	33	59	46	39	65	52	45	71	58	51	77	64	57
FM	76 to 108	38	25	18	44	31	24	50	37	30	56	43	36	62	49	42
TV Band I	41 to 88	34	–	24	40	–	30	46	–	36	52	–	42	58	–	48

Figure 7: Limits of conducted disturbance for voltage method, SOURCE: CISPR 25 [1]

In Figure 7 the LW band ranges from 0.15 MHz to 0.3 MHz. The attenuation at 0.3 MHz is 37 dB for attenuation class A5 when calculated using the formula provided in Table 1. The HV limits shown in Figure 6 are obtained by adding the 37 dB to LV limits shown in Figure 7. Test levels across different frequencies are determined using the values in the average column for the emission classes.

The calibration setup is shown in Figure 8. The input power is supplied to a coupling element between HV AN and optional impedance matching network either by injection probe (ISO 11452-4) or capacitive coupling (as defined in DCC method in ISO 7637-3). The EUT remains unpowered for calibration.



Key

1	EUT (or EUT simulator)	13	Power line filter
2	Reference ground plane	14	Shielded HV power supply (may be placed inside the shielded enclosure)
3	Low relative permittivity support ($\varepsilon_r \leq 1{,}4$) thickness 50 mm	15	Tracked RF test generator (may be placed inside the shielded box)
4	50 Ω load	16	Bulk head connector
5	Test signal coupling element (may be current clamp or capacitor)	17	Measuring instrument
6	HV supply lines (HV+, HV−)	18	High quality coaxial cable e.g. double shielded (50 Ω)
7	Additional shielded box	23	Ground straps
8	Impedance matching network (optional)		
10	HV AN		

Figure 8: Test setup for calibration of the test signal, SOURCE: CISPR 25 [1]

More details about the limits and calibration procedure can be found in subclause I.5.2.2 of [1]. The BCI (bulk current injection) EMS template in R&S®ELEKTRA is used to configure the reference calibration test settings to determine the input power levels needed for the desired test levels.

4.2.1.1 Input Power Level Calibration Test Template Configuration

The Table 3 shows the typical parameters for input power level calibration template.

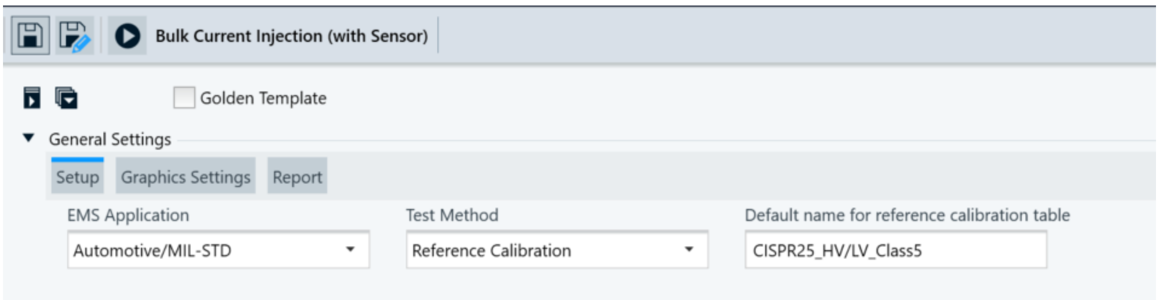
Parameter	Setting	Location in User Interface (UI)
EMS Application	Automotive/Mil-STD	General Setup => Setup
Test Method	Reference Calibration	General Setup => Setup
Default name for reference Calibration table	Assign a suitable name, CISPR25_HV/LV_Class5	General Setup => Setup
Level On	Sensor	Measurement Settings => Leveling Mode
Power Control	Forward Power	Measurement Settings => Leveling Mode
Level Conservation for Modulation	CW Carrier = Modulation Carrier	Measurement Settings => Leveling Options
Power Limitation	Not Active	Measurement Settings => Power Level Limitation
Frequency Range	150 kHz – 108 MHz	Subrange Header
Frequency Steps	1%, LOG	Subrange Header
Test Level	Limit line derived as per 4.2.1	Subrange => Test Level
Modulation	Off	UI not activated
Leveling Tolerance	0 dB – 0.4 dB	Subrange => Test Level
Sensor Device	Detector = Average Meas BW = 9 kHz	Subrange => Device Settings
System Monitoring	Test Level Transducer Forward Power	System Monitoring

Table 3: Typical parameters of input power level calibration template

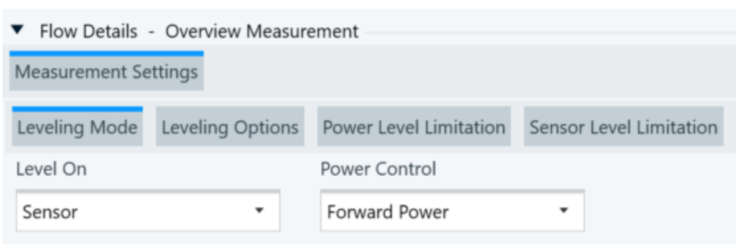
4.2.1.2 Input power level calibration template user interface preview

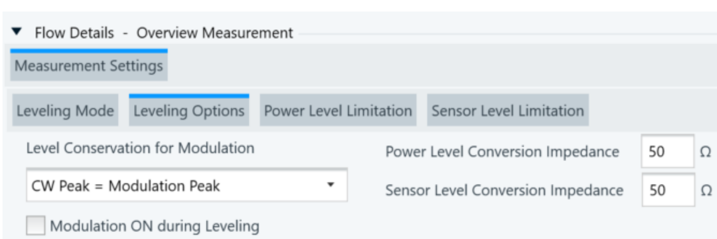
This section describes the UI for configuring various reference calibration testing parameters with the BCI template.

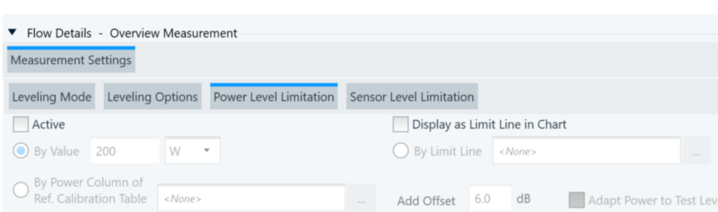
Configuring test method and standard



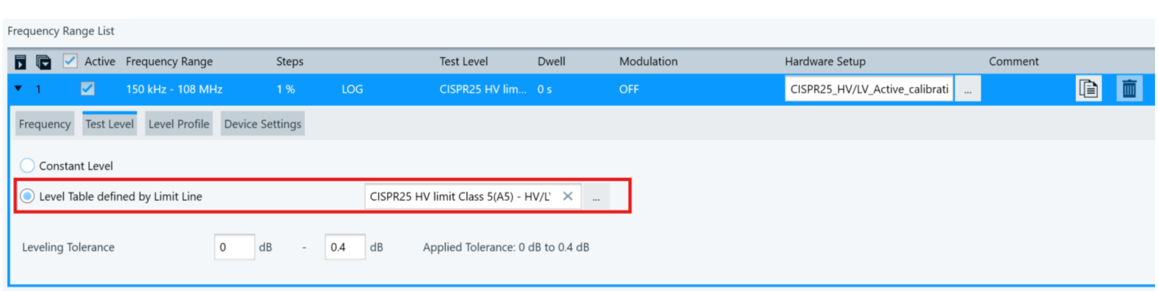
Configuring measurement settings



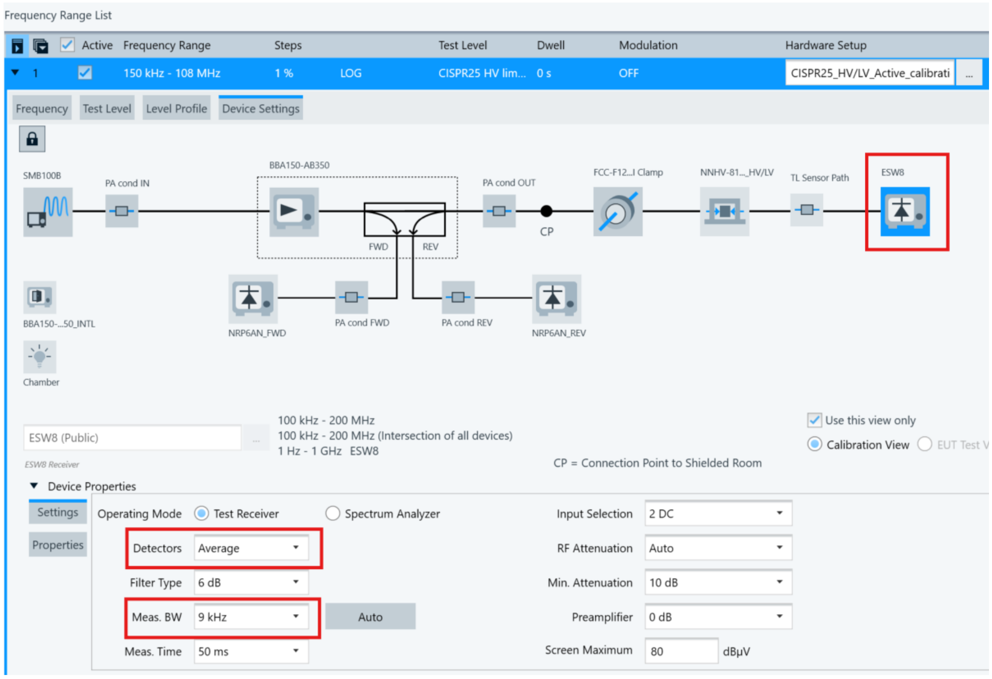




Configuring the subrange

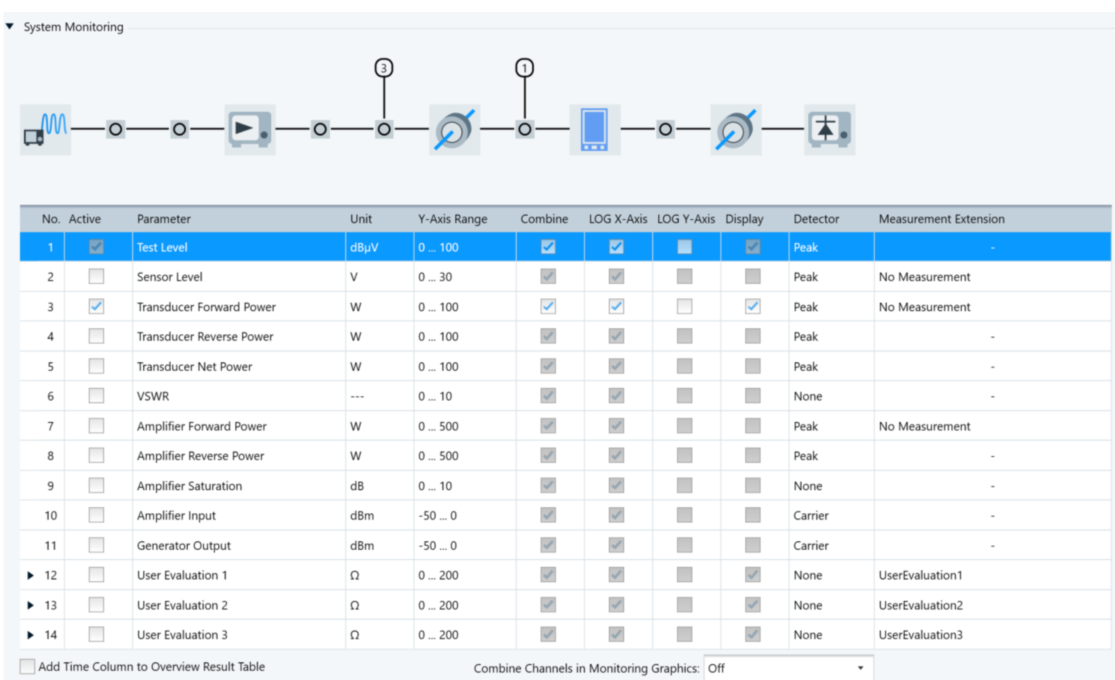


The limit line in the screenshot is created based on the description in 4.1.1.1.



As shown in the screenshot above, the detector is set to Average (can be set to Maximum Peak, see [1]), the BW is set to 9 kHz.

Configuring the system monitoring settings



4.2.1.3 Input power level Calibration test creation and execution

Click Create Test from Template in the reference calibration test template from 4.2.1.2 to create the reference calibration test in Figure 9.

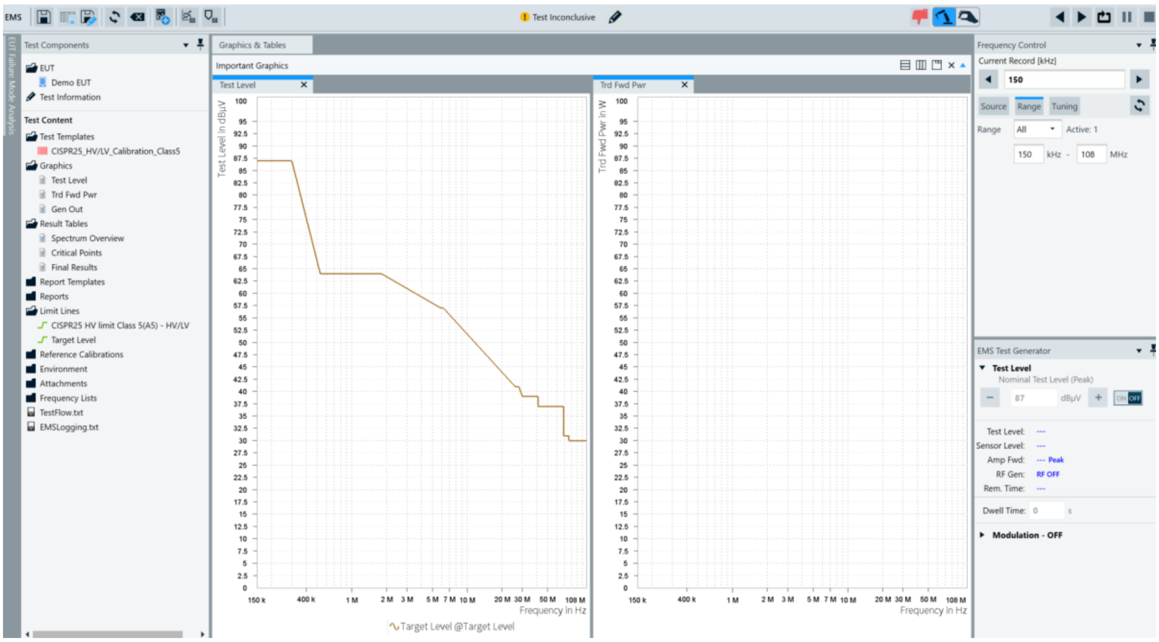


Figure 9: Input power level calibration test view.

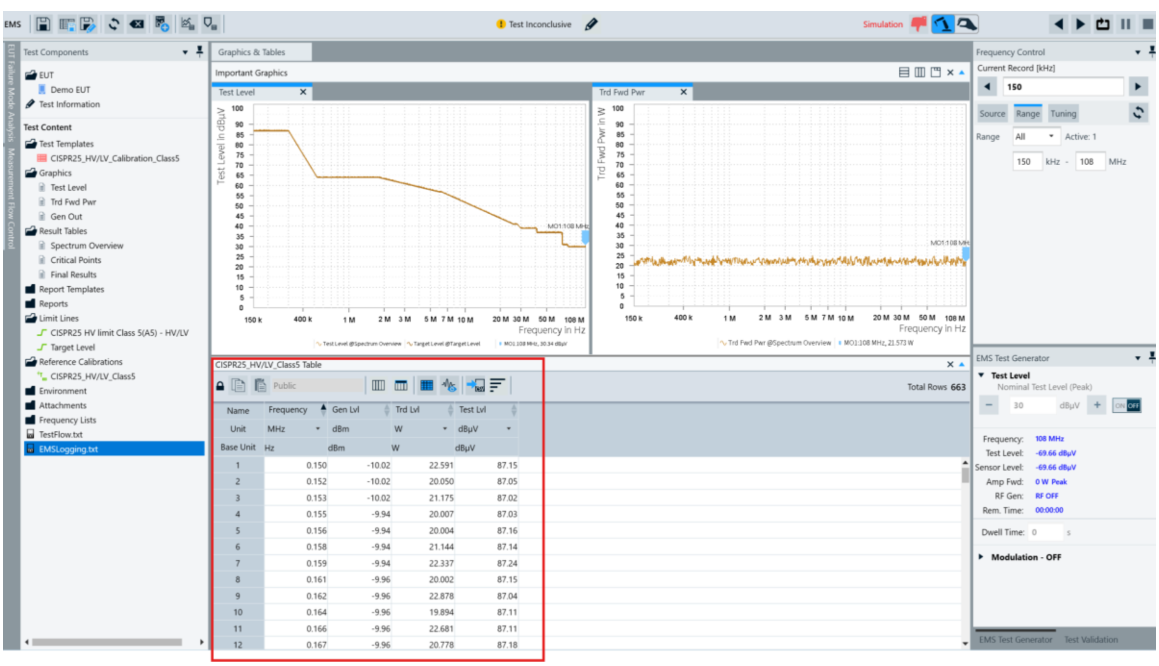


Figure 10: Input power level calibration test view after execution.

Figure 10 shows the test view displayed at the end of test execution. Upon saving the test, the user is prompted to save the reference calibration table for use during subsequent coupling attenuation measurement tests.

4.2.2 HV/LV conducted and HV-specific radiated emissions testing

The conducted and radiated emissions tests are conducted with setup in Figure 8.

There are two types of tests for measuring conducted emissions.

- Measuring disturbance voltage on the LV side.
- Measuring disturbance current on the LV harness side

The test setup, signal injection, measurement configurations and LV side emission limits for conducted emissions test are mentioned in subclause I.5.2.3 and I.5.2.4 of [1].

The HV-specific radiated emissions test measures the radiated emissions from the whole setup. The test setup, measurement configurations and emission limits for the radiated emissions are mentioned in subclause I.5.2.5.

The emissions limits for the tests above must not exceed the corresponding average LV emission limits (emission class should match the class used to determine the disturbance test levels during calibration)

4.2.2.1 Measuring the Emissions

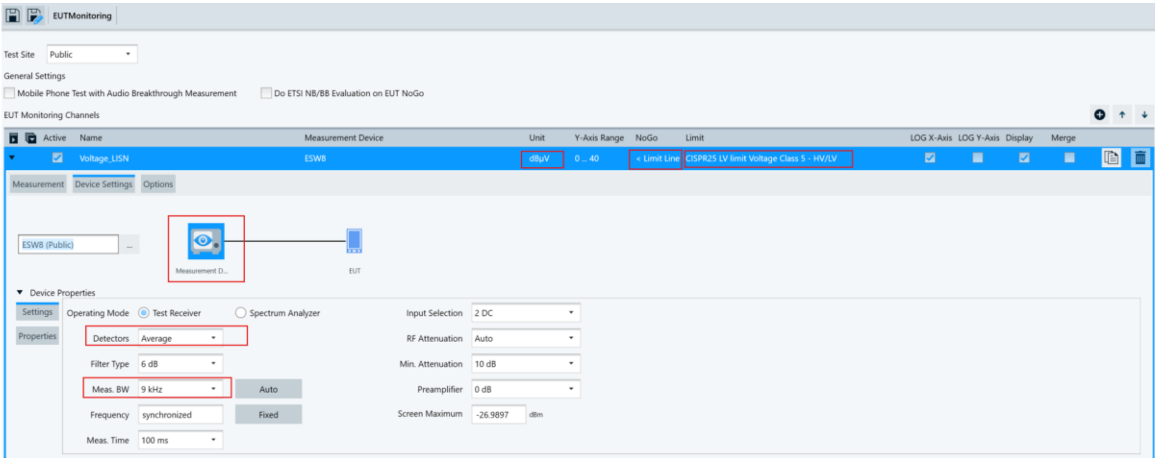
The emissions are measured by defining a monitoring channel in an EUT monitoring template. The measured values are compared with the LV emission limits for the emission measurements.

Table 4 shows the typical parameters for the EUT monitoring template with the three different emission measurements. The measurement limits, unit, transducer and transducer correction parameters are different in each case.

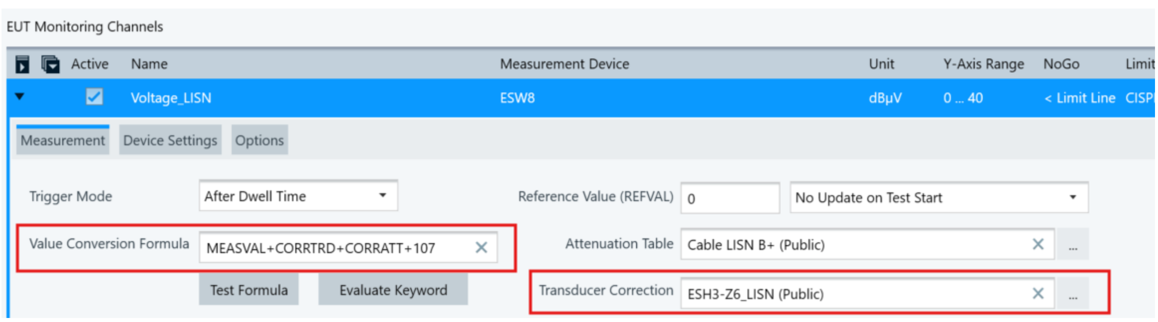
Parameter	Setting	Location in User Interface (UI)
Measurement Device	Frequency selective measuring device (Spectrum Analyzer)	Device Settings => Measurement Device
Unit	dbμV (Voltage method) dbμA (Current method) dbμV/m (Radiated Method)	Channel Header
Detectors	Average	Device Settings => Settings
Meas. BW	9 kHz	Device Settings => Settings
NoGo	< Limit Line	Channel Header
Limit Line	Voltage, Current, radiated emission class specific limit line (selection of EMI limit line is allowed, the average value column is used)	Channel Header
Value Conversion Formula	MEASVAL+CORRTRD+CORRATT+107	Measurement
Attenuation Table	Path specific cable	Measurement
Transducer Correction	Measurement specific correction (LISN, Current Probe, Antenna)	Measurement

Table 4: Typical parameters of emissions measurement in the EUT Monitoring Template

4.2.2.2 Emissions test EUT monitoring template user interface preview



The measurement device is a frequency-selective instrument, such as a spectrum analyzer.



The screenshots above illustrate the settings for voltage measurements. The current method and radiated emission settings are similar with specific changes indicated in

Table 4. The test setup, LV limits and display unit also vary. The algebraic formula in the value conversion formula user input area converts the measured value to a target result by applying the appropriate frequency specific attenuation and transducer corrections. The 107 in the formula is the conversion factor for converting power in dBm to voltage in dBµV, based on the relationship between power and voltage in a 50-ohm impedance system.

4.2.2.3 Emissions Test Template Configuration

Parameter	Setting	Location in User Interface (UI)
EMS Application	Automotive/Mil-STD	General Setup => Setup
Test Method	EUT Qualification	General Setup => Setup
EUT Monitoring Template	Assign a suitable template depending on measurement type (voltage, current, radiated)	General Setup => Setup
Level On	Substitution Method	Measurement Settings => Leveling Mode
Power Control	Forward Power	Measurement Settings => Leveling Mode
Reference Calibration Table	Assign the output table of test in 4.2.1.3	Measurement Settings => Leveling Mode
Level Conservation for Modulation	CW Carrier = Modulation Carrier	Measurement Settings => Leveling Options
Power Limitation	Not Active	Measurement Settings => Power Level Limitation
Frequency Range	150 kHz – 108 MHz	Subrange Header
Frequency Steps	1%, LOG	Subrange Header

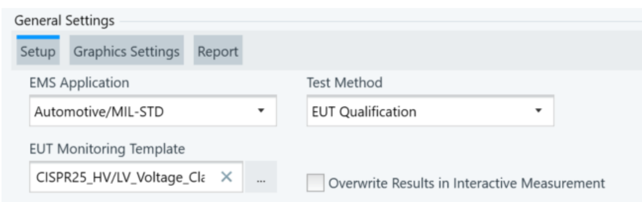
Parameter	Setting	Location in User Interface (UI)
Test Level	Limit line derived as per 4.2.1	Subrange => Test Level
Modulation	Off	UI not activated
Leveling Tolerance	0 dB – 0.4 dB	Subrange => Test Level
Sensor Device	Fwd Power Meter, Sensor Power Meter Meas BW = 9 kHz	Subrange => Device Settings
System Monitoring	Test Level Transducer Forward Power	System Monitoring

Figure 11: Typical parameters of emissions measurement in the EMS test template

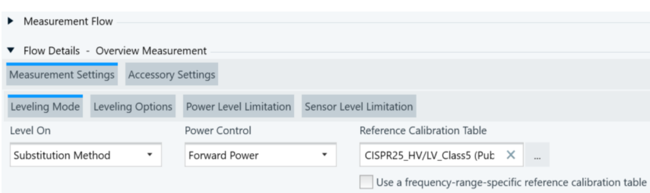
4.2.2.4 Emissions test template user interface previews

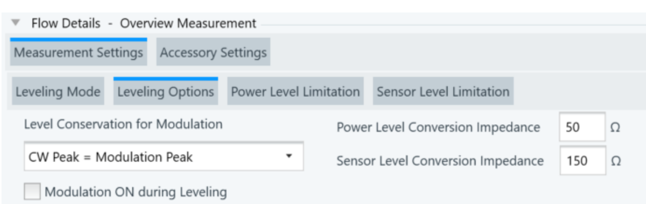
This section describes the UI for configuring the various HV/LV emissions measurement test parameters with the BCI template.

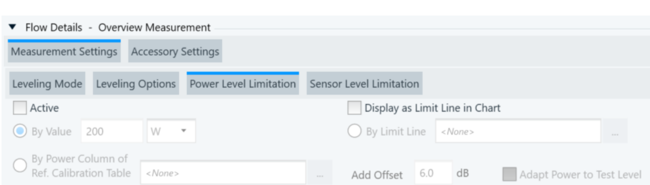
Configuring the test method and test standard



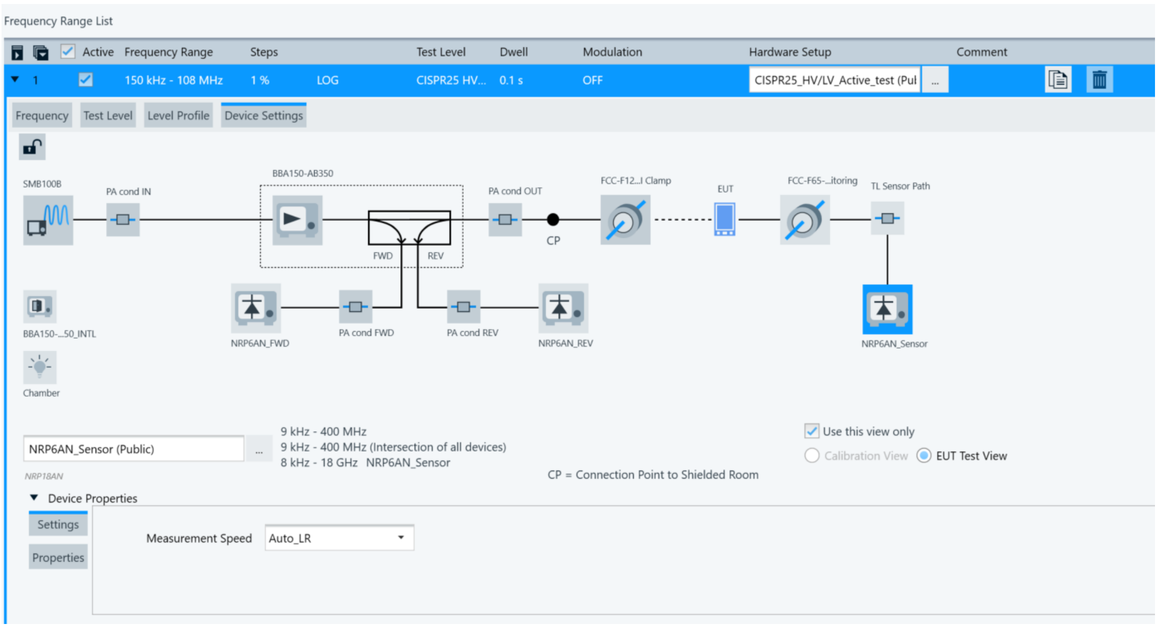
Configuring the measurement settings



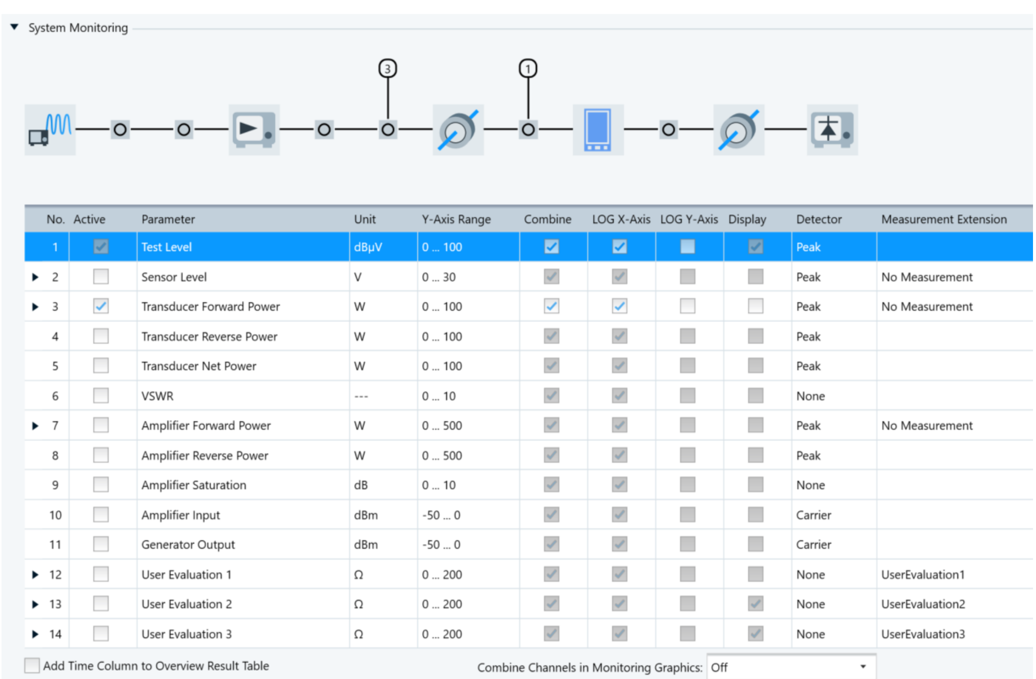




Configuring the subrange



Configuring the system monitoring settings



No.	Active	Parameter	Unit	Y-Axis Range	Combine	LOG X-Axis	LOG Y-Axis	Display	Detector	Measurement Extension
1	☑	Test Level	dBµV	0 ... 100	☑	☑	☐	☑	Peak	
2	☐	Sensor Level	V	0 ... 30	☑	☑	☐	☐	Peak	No Measurement
3	☑	Transducer Forward Power	W	0 ... 100	☑	☑	☐	☐	Peak	No Measurement
4	☐	Transducer Reverse Power	W	0 ... 100	☑	☑	☐	☐	Peak	
5	☐	Transducer Net Power	W	0 ... 100	☑	☑	☐	☐	Peak	
6	☐	VSWR	---	0 ... 10	☑	☑	☐	☐	None	
7	☐	Amplifier Forward Power	W	0 ... 500	☑	☑	☐	☐	Peak	No Measurement
8	☐	Amplifier Reverse Power	W	0 ... 500	☑	☑	☐	☐	Peak	
9	☐	Amplifier Saturation	dB	0 ... 10	☑	☑	☐	☐	None	
10	☐	Amplifier Input	dBm	-50 ... 0	☑	☑	☐	☐	Carrier	
11	☐	Generator Output	dBm	-50 ... 0	☑	☑	☐	☐	Carrier	
12	☐	User Evaluation 1	Ω	0 ... 200	☑	☑	☐	☐	None	UserEvaluation1
13	☐	User Evaluation 2	Ω	0 ... 200	☑	☑	☐	☑	None	UserEvaluation2
14	☐	User Evaluation 3	Ω	0 ... 200	☑	☑	☐	☑	None	UserEvaluation3

Configuring the excluded frequency bands

CISPR 25 includes limit lines with gaps because it focuses exclusively on radio frequency (RF) bands. If strictly following CISPR 25, calibration only needs to be performed in those frequency ranges where limits have been defined. Use the excluded frequency bands section to skip frequencies without specified limits.

Excluded Frequency Bands

No.	Active	Start Frequency	Stop Frequency	Band Name
1	☑	300 kHz	530 kHz	Band 1
2	☑	1.8 MHz	5.9 MHz	Band 2
3	☑	6.2 MHz	76 MHz	Band 3

4.2.2.5 Emissions measurement test creation and execution

Click on Create Test from Template in the reference calibration test template created in 4.2.2.4 to generate emission measurement using the EUT monitoring template as shown in Figure 12.

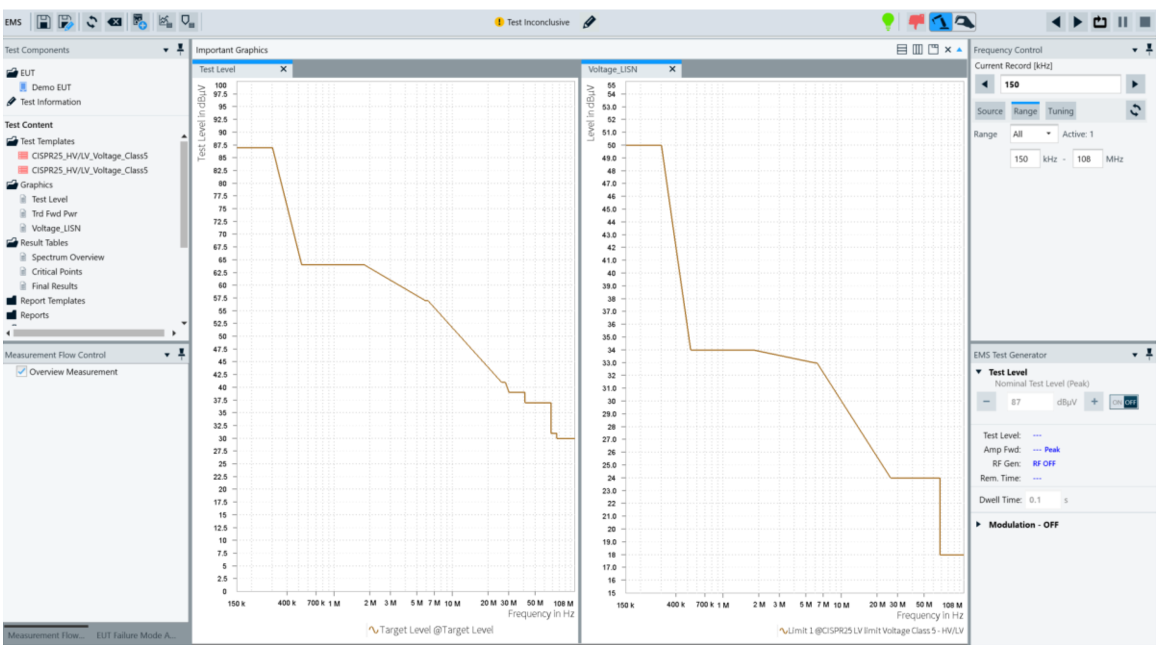


Figure 9

Figure 12: Emissions measurement test view.

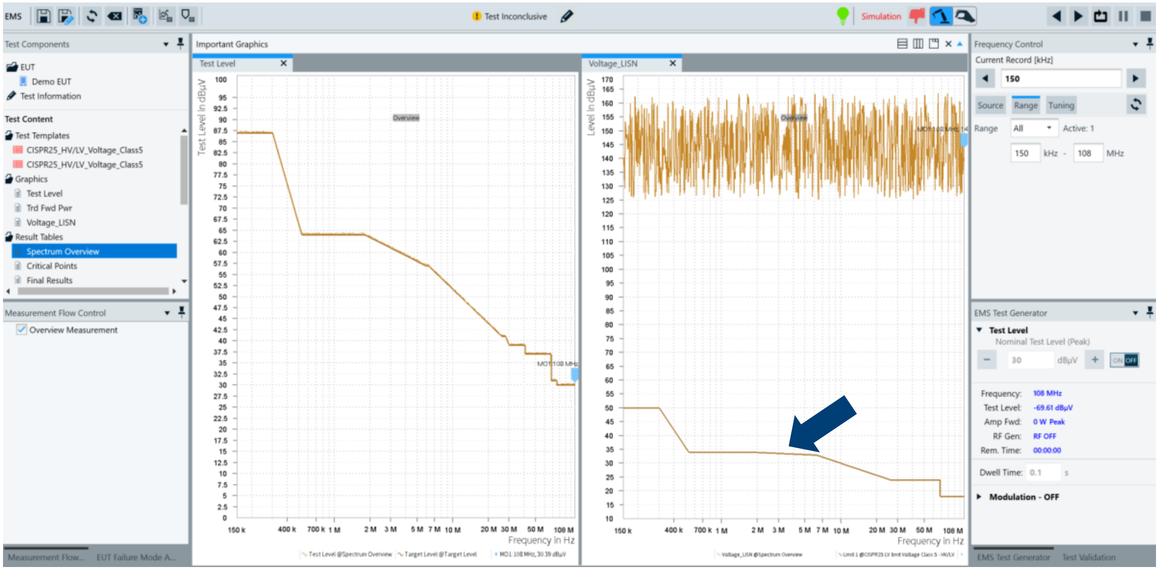


Figure 13: Emissions measurement test view after execution.

Figure 13 displays the test view at the end of test execution. The EUT monitoring channel readings must remain below the LV emission limits across all frequencies to pass.

This section presented the voltage emissions test. The current and radiated emissions tests are conducted in the same way with the test template from section 4.2.2.4 but with a different EUT monitoring template.

5 Reference documents

[1] CISPR 25 Edition 4.0 2016-10 Vehicles, boats, and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers

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