Application Note

MEASUREMENTS IN REVERBERATION CHAMBER WITH R&S® ELEKTRA

Products:

[1] R&S®ELEKTRA

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

Contents

1 Overview

Reverberation chambers (RVC) have become a popular alternative to anechoic chambers (AC) for electromagnetic emission and immunity testing. Unlike an AC, an RVC reflects waves to create a multipath environment. EMC testing with reverberation chambers is accepted in various EMC testing standards across different industries. An RVC is cost effective, generates high field strength, does not need excessive amplification, eliminates the need for complex antenna and DUT positioning for faster test speeds and accurately simulates real-world electromagnetic environments. Accurate and efficient testing demands specialized EMC test software for data acquisition, automation and analysis.

This application note describes how to setup R&S®ELEKTRA for measurements in an RVC.

2 Scope

This application note is based on R&S®ELEKTRA v5.20. The standards for conducting radiated immunity measurements supported with R&S®ELEKTRA v5.20 include:

– EN 61000-4-21 (mode tuned only)
– ISO 11452-11 (mode tuned only)
– ISO 11451-5 (Annex G: Reverb method with closed-loop power control)

This version of application note explains how to configure the hardware setup and test templates for the RVC calibration, equipment under test (EUT) checks and EUT testing in mode-tuned operation as well closed-loop power control.

3 R&S® ELEKTRA licenses

The following R&S ELEKTRA licenses and options are required for radiated immunity measurements with an RVC.

– Required
  - EMS test software (radiated) – ELEMS-R (for all options)
  - EMS rotating-tuner reverberation measurements – ELEMS-RVC (for calibration & mode tuned only)
  - EMS fast stirring reverberation measurement – ELEMS-FRVC (for Annex G: Reverb method with closed-loop power control)
– Optional
  - EMS extension to system – ELEMS-S (for EUT specific test plan definition, automated testing & summary reports)
  - EMS extension to automotive/MIL – ELEMS-AMEX (optional, required for ISO 11542-11 support)

4 Radiated immunity testing in mode-tuned operation

The mode-tuned operation is described in the IEC 61000-4-21 [1] & ISO 11542-11 [2]. It consists of the following steps.

– Chamber calibration procedures
– EUT test procedures

Before describing the chamber validation and EUT test procedures, let's examine the calibration setup.

4.1.1 Calibration setup

The calibration setup is described in the appropriate section of the EMC standard.

The RVC test volume is defined by the eight points where the isotropic field probe is placed during calibration, see Figure 1. The test volume maintains a distance of at least λ/4 away from the chamber walls and any other metallic object (antenna or stirrers) within the chamber.

The isotropic field probe is positioned at the first corner of the test volume and every axis of the triaxial field probe points inside the test volume. The receiving antenna is positioned inside the test volume. It points to a random location outside of the test volume and is cross polarized with the transmitting antenna.

During calibration, the lower frequency range utilizes the log-per antennas, and the upper frequency ranges the horn antennas.

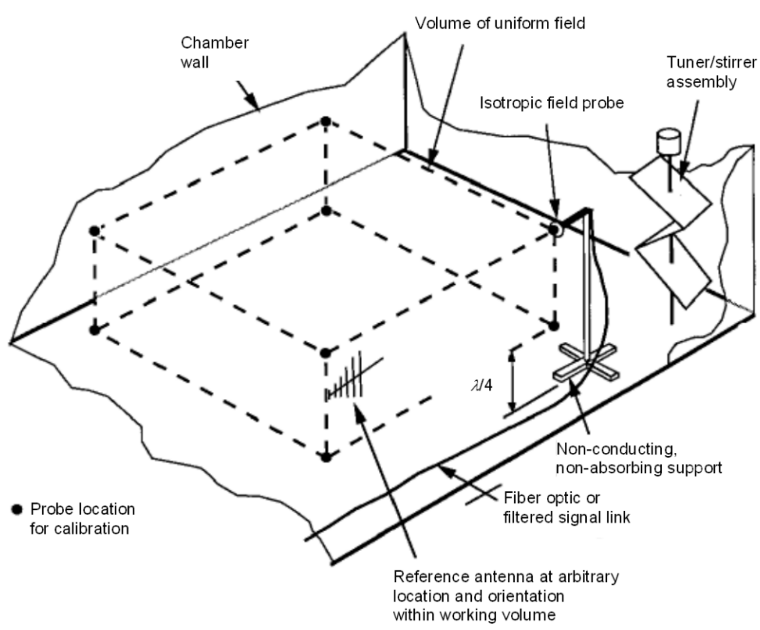


Figure 1 Test volume in RVC, SOURCE: IEC 61000-4-21 [1]

4.2 Mode-tuned chamber validation procedures

The chamber calibration procedures consist of three steps.

– Unloaded chamber testing is where the chamber field uniformity and input power requirements are determined with no EUT in the chamber. The test volume of the chamber is completely empty except for the necessary tri-axial field probes, transmit antenna, receive (reference) antenna and their cabling. All extra equipment (video monitoring system, foam test table) are removed. The calibration only needs to be done when a chamber is installed or after major modifications.

– Loaded chamber testing is where the chamber field uniformity and input power requirements are checked by simulated maximum loads. Along with tri-axial field probes, transmit antenna and receive (reference) antenna, the chamber is filled with absorbing material and fully loaded. Equipment that will be used for EUT testing can be added back to the chamber (video monitoring equipment, foam test table). The calibration only needs to be done when a chamber is installed or after major modifications.

– EUT check where chamber is calibrated with EUT in place and the chamber validation factor (CVF, or average to input power ratio similar to the antenna validation factor (AVF) for an unloaded chamber) is computed. The chamber loading factor (CLF) is derived from the CVF and AVF. The calibration is performed before every EUT test.

Unloaded and loaded chamber measurements check whether the reverberation chamber meets the requirements for statistically uniform field distribution and determines the chamber limits (maximal loading). This data is required for the EUT check and measurement.

During the unloaded and loaded chamber testing, the max E-field values (E_x, E_y, E_z) are measured with the E-field probe, maximum and average received power are measured with the reference antenna and input power (forward power averaged over a tuner rotation) for each frequency, stirrer position and field probe/antenna location. The standard deviation for each probe axis and total data set (all probe axis) are determined from the E-field measurements. The standard deviations should not exceed the limits defined in the standard for the individual and total probe axis.

The average received power is used to compute the

- Receive AVF
- Chamber quality factor.
- Time constant for the chamber (derived from quality factor and needed to confirm the chamber is suitable for desired pulse waveform testing)
- Power needed to generate the test levels.

The maximum of the received power is used to compute.

- Estimated E field
- Insertion loss (IL) in loaded chamber test
- Maximum load factor (ratio of AVF_{Empty} to AVF_{Loaded})

Only the received power is measured during chamber validation with the EUT in place. E-field measurements with the probe are not required. The loading factor presented by the EUT should be lesser than the maximum loading factor derived during loaded chamber test. The CVF (average to input power ratio as with the AVF for the unloaded chamber) is computed. From the CVF and AVF_{Empty}, the chamber loading factor (CLF) is derived. The CLF should be less than the maximum loading factor for all frequencies. A value for the minimum pulse width is calculated. The applied pulse width shall not be below this value to inject sufficient power into the RVC.

Users should consult the appropriate sections in [1] and [2] for in-depth understanding of the concepts.

4.3 Mode-tuned EUT testing

The EUT test procedures consist of

– EUT Qualification & Susceptibility tests as per standards. The forward input power required to set up the E-field at every test frequency is derived from the average normalized maximum E-field of unloaded chamber calibration and CLF derived with the EUT in place.

4.4 Mode-tuned hardware setup configuration

The hardware setup describes the devices used in a measurement and how they work together. The hardware setup is created manually. Figure 2 below shows a setup as described in the standard.

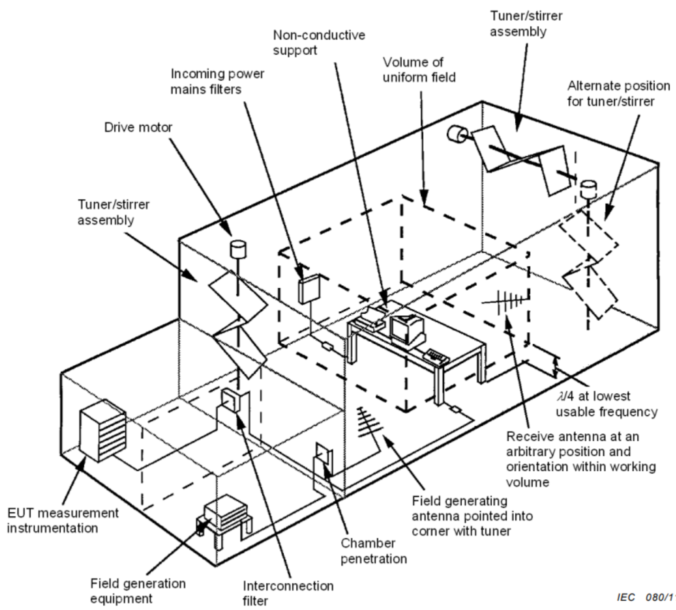


Figure 2 General test setup for measurements in RVC, SOURCE: IEC 61000-4-21 [1]

In R&S®ELEKTRA, the radiated hardware setup for the reverberation chamber is used for the recommended hardware setup in the standard. Figure 3 & Figure 4 shows the Calibration & EUT view of a hardware setup with four subranges.

- Calibration View (200 MHz – 7.125 GHz) shown below in Figure 3

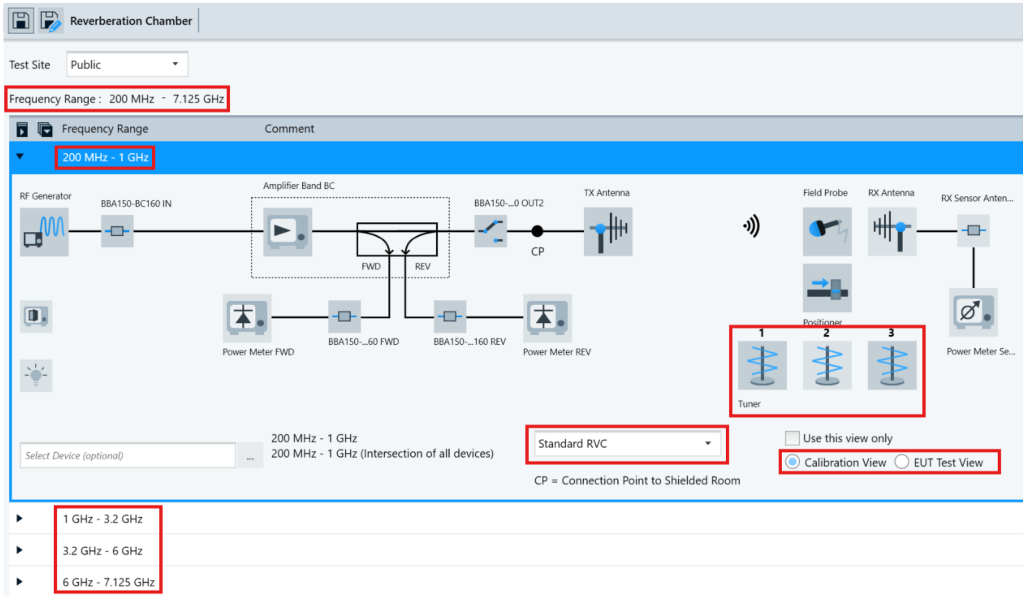


Figure 3 Calibration view (200 MHz – 7.125 GHz) of hardware setup for mode-tuned test.

- EUT Test View (200 MHz – 7.125 GHz) shown below in Figure 4

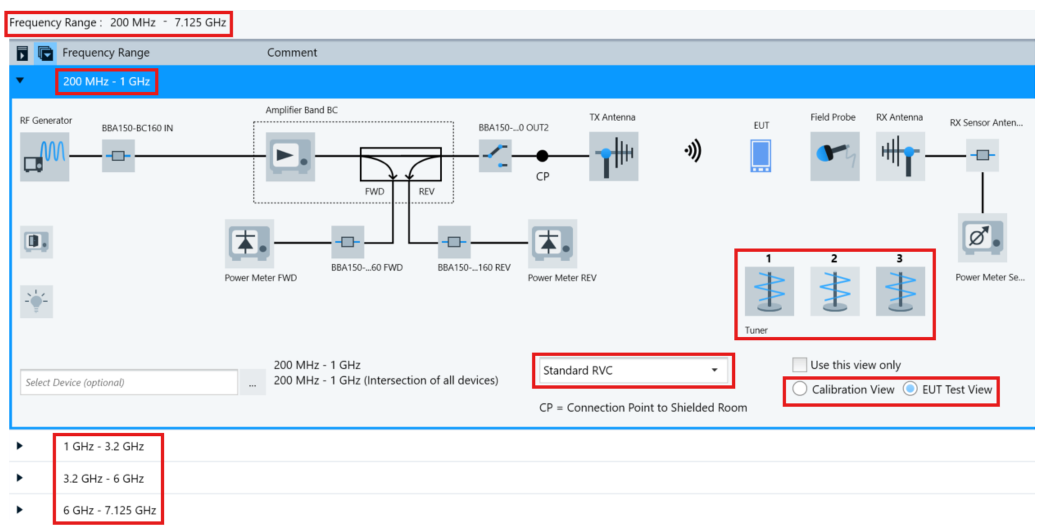


Figure 4 EUT view (200 MHz – 7.125 GHz) of hardware setup for mode tuned test.

Each subrange in the hardware setup is configured with devices matching the subrange. For mode-tuned testing, the hardware is configured in the standard RVC mode that supports up to three tuners for better mode density and field uniformity.

The Table 1 shows the devices must be selected from the device list and assigned to the respective placeholders.

Device Name	Device Category/Type	Special Settings
RF Generator	Generator	No specific requirements.
Amplifier Band A	Amplifier	Depending on whether a directional coupler is used, the value of the directional coupler attenuation must be appropriately measured and set. If necessary, multiple amplifiers may be used to cover the measured frequency range.
Power Meter FWD	Power Meter	If a two-channel power meter is used channel A shall be set for the measurement of the forward power.
Power Meter REV	Power Meter	If a two-channel power meter is used, channel B shall be set for the measurement of the reverse power. If the power meter supports dual channel measurement (coupling of channel B to A), the feature should be activated to improve the measurement speed.
Tx Antenna Rx Antenna	Antenna	Enter the frequency parameters for each antenna and the respective antenna efficiency factor. Antenna efficiency is the ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter.
Tuner (1, 2, 3)	Comtest tuner or generic turntable	Comtest is a manufacturer of tuners for the RVC. Comtest tuners are classified as a type of turntable. Configuration requires a minimum of one tuner and allows a maximum of three
Field Probe		The field probe must support the simultaneous measurement of all three axes. Enter the values of the probe calibration (frequency response and linearity correction) if available.
Power Meter Sensor	Power meter/spectrum analyzer	No specific requirements.
Switch unit		The signal paths of the switching unit with their respective settings are defined here
Interlock		An interlock device must always be available in the device list. If no physical device is available, select NONE.
Positioner	Positioner/manual positioner	Manual positioner to prompt user to change the Rx antenna /field probe position (only in calibration view)

Table 1 Devices used in hardware setup for mode-tuned test.

Depending on the power needed, multiple amplifiers can cover the frequency range. Typically, transmit and receive antennas are required. Logarithmic periodical antennas are used for frequency ranges up to 1 GHz. Horn antennas are used to cover frequencies above 1 GHz. The transmit antennas should not point to a corner of the chamber and their position should not be changed after calibration is completed.

Either NRX or single probes are used to measure the transmitted antenna forward and reverse power,

The generated field strength is measured by the field probe and a receive antenna connected to the spectrum analyzer/field probe used to measure the received power.

4.5 Mode-tuned test template configuration and test execution

The following sections describe the test template configuration for the different calibration & EUT tests. The hardware setup must be created before configuring test templates.

4.5.1 Mode-tuned unloaded chamber test template configuration

Table 2 shows the typical parameters configured for the unloaded chamber test template for ISO 11452-11 test standard. This configuration applies to EN 61000-4-21 standards as well.

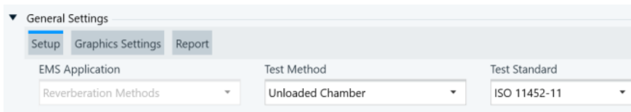
Parameter	Setting	Location in User Interface (UI)
EMS Application	Reverberation Methods	General Setup => Setup
Test Method	Unloaded Chamber	General Setup => Setup
Test Standard	ISO 11452-11	General Setup => Setup
Level On	Transducer Power	Measurement Settings => Leveling Mode
Power Control	Forward Power	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	200 MHz – 7.125 GHz	Subrange Header
Frequency Steps	5.6%, LOG (200 MHz – 600 GHz) 5.6%, LOG (600 MHz – 1 GHz) 5.6%, LOG (1 GHz – 1.2 GHz) 5.2% LOG (1.2 GHz – 2 GHz) 1.45% DECLIN (2 GHz – 7.125 GHz)	Subrange Header
Test Level	5 W	Subrange => Test Level
Modulation	Off	UI not activated
Leveling Tolerance	0 dB – 0.4 dB	Subrange => Test Level
Tuner	12	Subrange => Reverb Settings
Sensor	8	Subrange => Reverb Settings
Accessory Settings	Priority 1 => Frequency Priority 2 => Tuner Priority 3 => Position (Sensor)	Accessory Settings
Input Evaluation Data	Tolerance of Standard Deviation: ISO 11452-11 Max Std Deviation Chamber Volume: 179.237 m^3 (depends on chamber) Relative Permittivity: 8.8595 pF/m (depends on chamber)	Data Evaluation => Input Data
Output Evaluation Data	Calibration Result Table: ISO 11452-11 Unloaded Chamber Norm Max E-Field Table: LUF200 Averaged Max E-Field E&C	Data Evaluation => Output Data
Evaluation Graphics	Insertion Loss Standard Deviation Antenna Correction Factor E-Field Comparison Chamber Q	Data Evaluation => Evaluation Graphics
System Monitoring	Test Level Received Antenna Power Sensor Level Transducer Reverse Power	System Monitoring

Table 2 Typical parameters in mode-tuned unloaded chamber test template

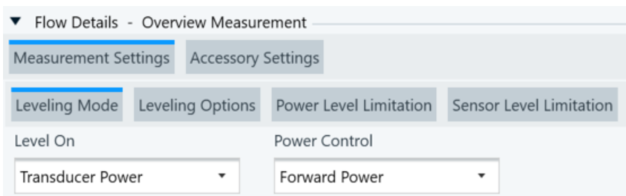
4.5.1.1 Unloaded chamber test template user interface previews

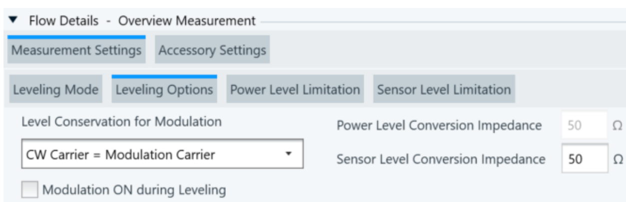
In this section, the UI to configure various parameters of unloaded chamber listed in Table 2 are shown.

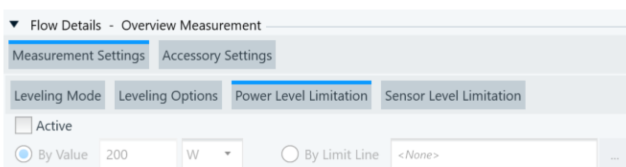
Configuring the test method and test standard



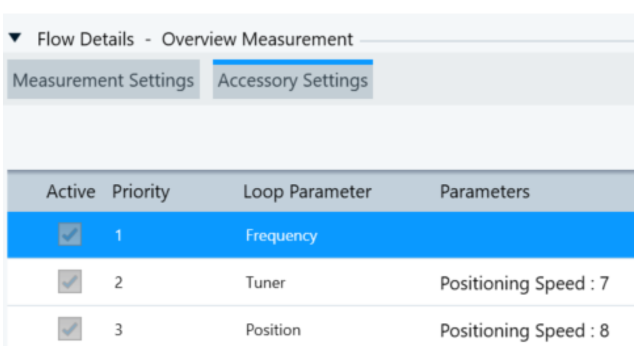
Configuring the measurement settings





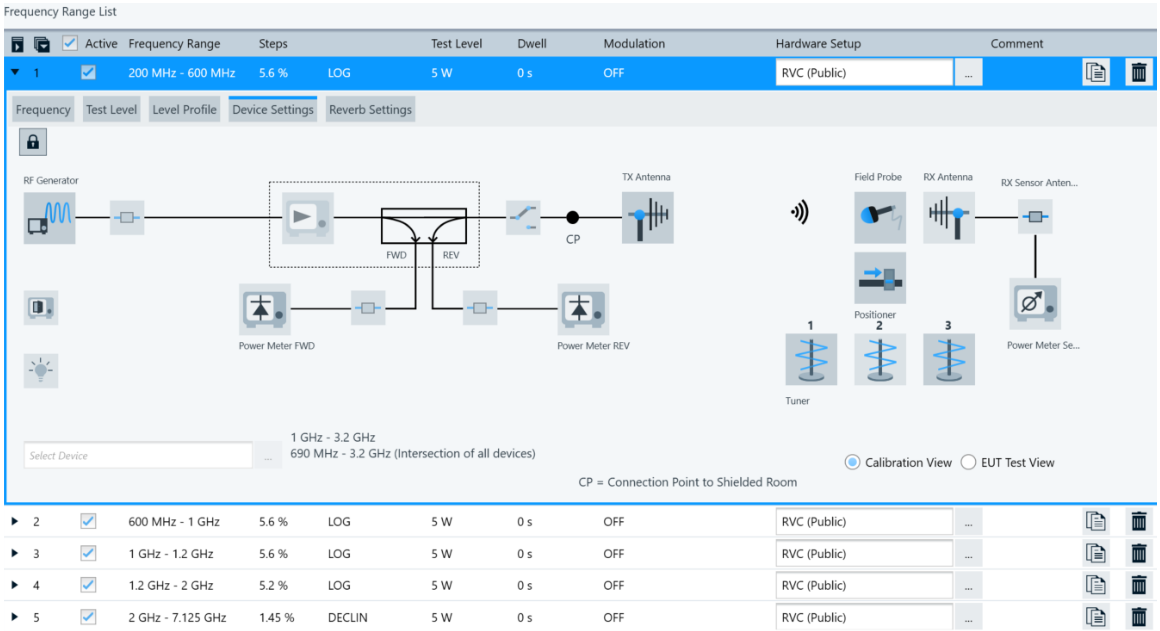


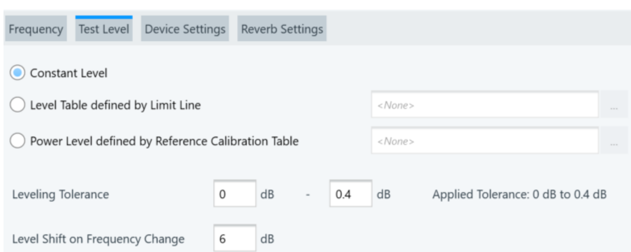
Configuring the accessory settings

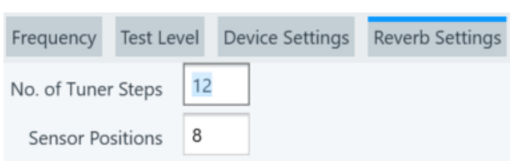


As shown above, an unloaded chamber test is performed for various combinations of tuner and sensor positions.

Configuring the subrange



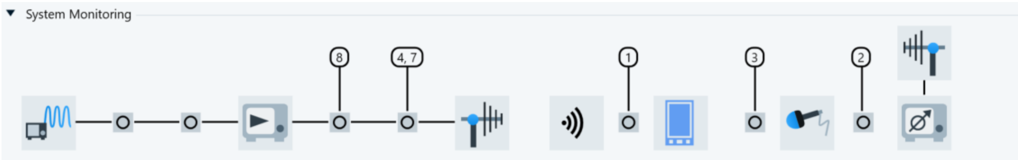




If multiple tuners are configured, each position is defined by a unique combination of tuner positions.

In the examples above, Tuner 2 is configured, and its position—relative to the tuner step—is calculated using the highlighted formula. The same calculation applies if Tuner 3 is configured. The relative positions of the tuners are set to increase the number of independent positions, helping to achieve a statistically uniform electromagnetic field.

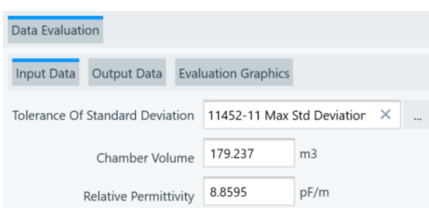
Configuring the system monitoring



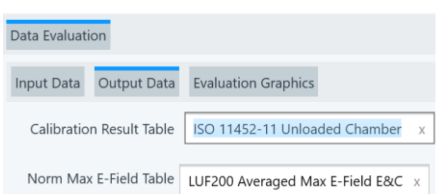
No.	Active	Parameter	Unit	Y-Axis Range	LOG X-Axis	LOG Y-Axis	Display	Detector	Measurement Extension
1	☑	Test Level	W	0 ... 20	☑	☐	☑	Carrier	
2	☑	Received Antenna Power	dBm	-20 ... 30	☑	☐	☑	Carrier	
3	☑	Sensor Level	V/m	0 ... 100	☑	☐	☑	Carrier	Measure all Field Sensor Axes
4	☑	Transducer Forward Power	W	0 ... 20	☑	☐	☑	Peak	No Measurement
5	☐	Transducer Reverse Power	W	0 ... 100	☑	☐	☐	Peak	
6	☐	Transducer Net Power	W	0 ... 100	☑	☐	☐	Peak	
7	☑	VSWR	---	0 ... 10	☑	☐	☑	None	
8	☑	Amplifier Forward Power	W	0 ... 20	☑	☐	☑	Peak	No Measurement
9	☐	Amplifier Reverse Power	W	0 ... 500	☑	☐	☐	Peak	
10	☐	Amplifier Saturation	dB	0 ... 10	☑	☐	☐	None	
11	☐	Amplifier Input	dBm	-50 ... 0	☑	☐	☐	Carrier	
12	☐	Generator Output	dBm	-50 ... 0	☑	☐	☐	Carrier	
16	☐	Insertion Loss	dB	0 ... 100	☑	☐	☐	None	

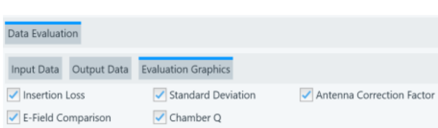
☐ Add Time Column to Overview Result Table ☑ Combine Channels in Monitoring Graphics

Configuring the data evaluation



Chamber volume and relative permittivity are used to calculate the quality factor (Q-factor) for the chamber using the average power measurements. Relative permittivity is used for estimating the Q-factor from the averaged field strength readings.





4.5.2 Mode-tuned unloaded chamber test

4.5.2.1 Test creation

The first step of the RVC calibration process verifies the field strength distribution in the test volume of the unloaded chamber. Before the test starts, the field probe is positioned at sensor position 1 (the single axis points into the test volume). The receive antenna is placed in a random position inside the test volume (note: the receive antenna should have no direct radiating path to the transmit antenna and that it should also be cross polarized to the transmit antenna).

Click “create test from template” in the unloaded chamber test template to create the unloaded chamber test as shown in Figure 5. In the measurement flow control, the test flow is grouped based on the antenna/tuner positions. In the example shown in Figure 5 , all subranges used the same transmit antenna and the same number of tuner/sensor positions. If the antenna or tuner positions are different in the few subranges, the measurement flow will be grouped based on antenna/tuner steps to optimize the test flow.

Figure 5 Unloaded chamber test view for mode-tuned test.

4.5.2.2 Test execution

The RVC calibration runs with several measurement loops. As in 4.5.1.1, the accessory settings are defined for three accessories (frequency, tuner and position/sensor). Additionally, if the templates in the hardware setup use multiple antennas, the software groups and executes subranges based on the antenna. Combining various accessories creates many repetitions with unique accessory positions. Some accessory settings do not require any user interaction, but others like the sensor position, or the subrange antenna, must be set manually and the dialog shown in Figure 6 will appear.

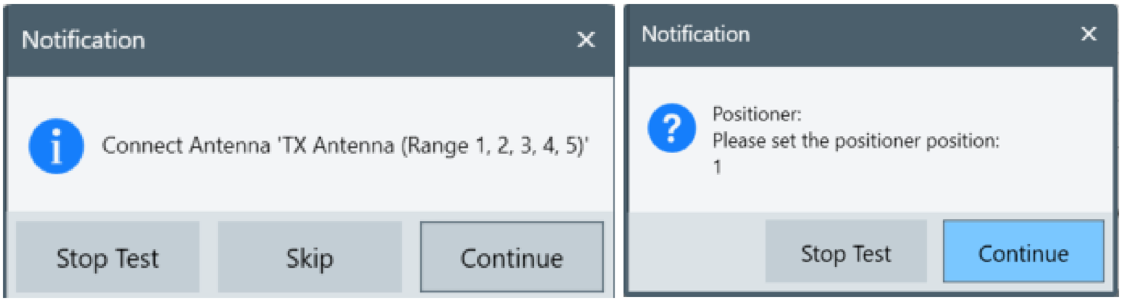


Figure 6 User dialog during mode-tuned unloaded calibration Test.

The measurement run has two distinct phases:

– The data collection phase is where the test levels are set at every frequency/tuner/sensor position and the system monitoring points are measured. After each completed scan, the measurement results are copied to the loop results folder.

– The data evaluation phase is where the evaluation generates an unloaded chamber evaluation result table (Figure 8) and a transducer correction average normalized E-field table (see Figure 9). In the average normalized E-field table, the unloaded insertion column is occupied during this test run. The evaluation graphics selected in the template are also generated.

During the run of the measurement, the current state of the measurement loops, accessory movements, test levels are displayed in the respective panels as shown in Figure 7.

Figure 7 Unloaded test view during mode-tuned measurement.

Figure 8 shows the various columns of the unloaded test calibration results and

Table 3 describes the unloaded chamber result columns.

ISO 11452-11 Unloaded Chamber Table

Total Rows

Name	Rg	Freq...	CCF	Insertion...	Standard...	Standar...	Standard...	Standard Deviation XYZ	Input Level	Avg Re...	P Max Rec	Avg Norm Ma...	Estimated E-...	E-Field D...	Chamber Q(E)	Chamber Q(P)
Unit		MHz	dB	dB	dB	dB	dB	dB		dBm	dBm	(V/m)/√(W)	(V/m)/√(W)	dB		
1	1	200.000	14.62	9.54	3.14	2.67	2.17	2.47	5.327	22.64	30.79	15.558	14.077	0.87	246.085159	515.351074
2	1	211.200	15.91	10.67	1.85	2.61	2.30	2.24	5.398	21.41	29.71	11.822	12.992	-0.82	169.970078	450.974487
3	1	223.027	15.30	11.33	2.27	2.65	2.07	2.31	5.327	21.97	28.55	12.335	12.695	-0.25	193.774078	611.958130
4	1	235.517	16.11	11.81	1.25	1.80	2.03	1.72	5.345	21.17	27.46	12.121	12.831	-0.49	186.498566	597.659180
5	1	248.706	15.79	11.16	2.29	2.61	1.31	2.32	5.305	21.46	28.47	15.427	14.510	0.53	296.428497	757.921814
6	1	262.633	17.43	13.34	2.02	2.45	1.15	1.93	5.266	19.78	24.87	14.234	12.220	1.33	275.190063	611.156921
7	1	277.341	16.92	12.83	2.75	2.67	1.98	2.38	5.281	20.31	26.02	15.140	13.524	0.98	341.051697	809.423828
8	1	292.872	17.34	13.34	2.50	1.99	1.91	2.20	5.296	19.90	26.29	13.985	13.386	0.38	320.614838	866.265991
9	1	309.273	18.44	14.22	1.66	1.33	2.14	1.73	5.290	18.80	25.23	12.853	12.838	0.01	257.889038	791.664246
10	1	326.592	19.24	14.66	1.83	1.25	2.83	1.97	5.304	18.00	24.18	12.429	12.960	-0.36	270.859833	774.676208
11	1	344.881	20.21	15.62	1.95	1.53	1.49	1.78	5.318	17.05	24.24	12.586	12.105	0.34	343.578430	729.811584

Figure 8 Unloaded Chamber Calibration Result of mode tuned test

Column Name	Description	Unit
Rg	Subrange number	None
Frequency	frequency	Hz
CCF	Chamber correction factor (B.8)	dB
Insertion Loss	Insertion loss (B.9)	dB
Standard Deviation X, Y, Z	Standard deviation of the E-field for the x axis in dB (B.4 & B.5)	dB
Standard Deviation XYZ	Standard deviation of the E-field for the x axis in dB (B.6 & B.7)	dB
P_{input}	Input power into the transmitting antenna	dBm
P_{AveRec}	Average power received by the receiving antenna measured with the receiver device	dBm
P_{MaxREC}	Maximum power received by the receiving antenna measured with the receiver device	dBm
Avg Norm Max E-field	Calculated average normalized maximum E-field (B.3) in V/m	V/m/SQR(W)
Estimated E-field	Estimated E-field using the maximum received power (A.6)	V/m/SQR(W)
E-field Delta	Difference between average normalized max E-field and estimated E-field columns	dB
Chamber Q(E)	Estimated chamber Q factor using the chamber volume, the chamber wall permittivity, and the averaged field strength values	None
Chamber Q(P)	Calculated chamber Q factor using the chamber volume, the chamber wall permittivity, and the averaged power	None

Table 3 Unloaded calibration result table column description of mode-tuned test.

Figure 9 shows the various columns for the average normalized E-field table and Table 4 describes the average normalized E-field table columns based on [1]. The insertion loss (unloaded) column is populated during this test run.

LUF200 Averaged Max E-Field ISO Table

Name	Frequency	Avg Norm Max E-Field	Insertion Loss Unloaded	Insertion Loss Loaded
Unit	MHz	(V/m)/√(W)	dB	dB
Interpolation	Logarithmic	Linear	Linear	Linear
1	200.000	15.558	9.54	0.00
2	211.200	11.822	10.67	0.00
3	223.027	12.335	11.33	0.00
4	235.517	12.121	11.81	0.00
5	248.706	15.427	11.16	0.00
6	262.633	14.234	13.34	0.00
7	277.341	15.140	12.83	0.00
8	292.872	13.985	13.34	0.00
9	309.273	12.853	14.22	0.00
10	326.592	12.429	14.66	0.00
11	344.881	12.586	15.62	0.00
12	364.194	12.679	14.39	0.00
13	384.589	11.108	15.84	0.00
14	406.126	11.542	15.64	0.00
15	428.869	13.529	17.31	0.00
16	452.886	12.768	16.33	0.00
17	478.247	11.190	19.57	0.00
18	505.029	12.029	18.24	0.00
19	533.311	13.503	17.88	0.00
20	563.176	12.943	19.84	0.00
21	594.714	11.528	19.61	0.00
22	600.000	14.172	19.77	0.00
23	600.000	14.168	19.77	0.00
24	633.600	11.658	19.79	0.00
25	669.082	12.078	21.01	0.00
26	706.550	12.275	21.00	0.00
27	746.117	12.096	20.31	0.00
28	787.900	12.384	22.71	0.00
29	832.022	12.148	24.35	0.00
30	878.615	12.236	23.89	0.00
31	927.818	12.688	24.61	0.00

Figure 9 Average normalized E-Field table after mode tuned unloaded calibration test

Column Name	Description	Unit
Frequency	Frequency	Hz
Avg Norm Max E-field	Calculated average normalized maximum E-field (B.3) in V/m	V/m/SQR(W)
Insertion Loss (unloaded)	Insertion loss (B.9)	dB

Table 4 Average normalized E-Field table column description

Figure 10 shows the various evaluation graphics generated during the data evaluation phase. The graphics are stored in the evaluation graphics folder in the test content explorer.

Figure 10 Unloaded chamber evaluation graphics of mode-tuned test.

4.5.3 Mode-tuned loaded chamber test template configuration

The typical parameters for the loaded chamber are largely identical to those of the unloaded chamber, except for the test method and evaluation settings. The following table includes the parameter changes in compared to the unloaded chamber.

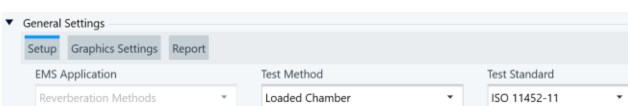
Parameter	Setting	Location in User Interface (UI)
Test Method	Loaded Chamber	General Setup => Setup
Input Evaluation Data	Tolerance of Standard Deviation: ISO 11452-11 Max Std Deviation Chamber Volume: 179.237m^3 (depends on chamber) Relative Permittivity: 8.8595 pF/m (depends on chamber) Norm Max E-Field Table: LUF200 Averaged Max E-Field Example (Public)	Data Evaluation => Input Data
Output Evaluation Data	Calibration Result Table: ISO 11452-11 Loaded Chamber	Data Evaluation => Output Data
Evaluation Graphics	Insertion Loss Standard Deviation Antenna Correction Factor Maximum Loading Factor Chamber Q	Data Evaluation => Evaluation Graphics

Table 5 Typical parameters of loaded chamber test template for mode-tuned test

4.5.3.1 Loaded chamber test template user interface previews

In this section, the UI for various parameters of loaded chamber listed in Table 5 are shown.

Configuring the test method and test standard



Configuring the measurement settings

The measurement settings are like those for the unloaded chamber test template.

Configuring the accessory settings

The accessory settings are like those of the unloaded chamber test template.

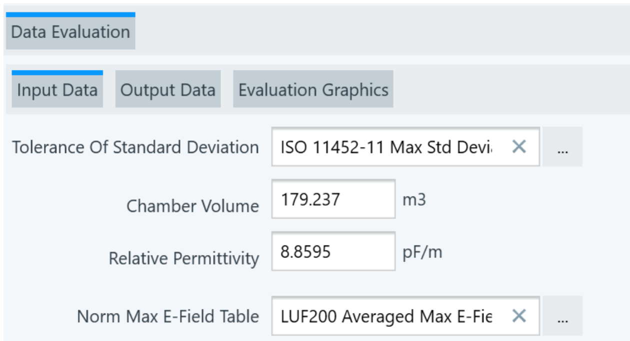
Configuring the subrange

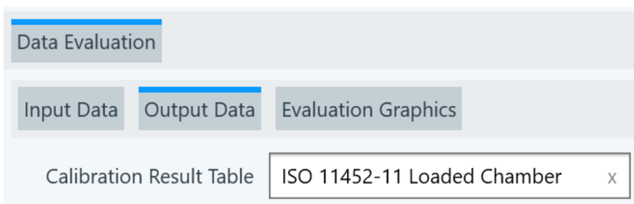
The subrange settings are like those of the unloaded chamber test template.

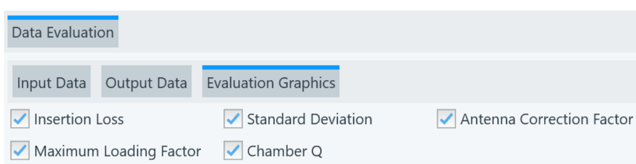
Configuring the system monitoring settings

The system monitoring settings are like those of the unloaded chamber test template.

Configuring the data evaluation







4.5.4 Loaded chamber test execution

The loaded chamber test creation and execution form the second step of reverberation chamber calibration process. The tests resemble the unloaded chamber test but the field strength distribution in the test volume of the fully loaded chamber is verified. The receiving antenna is placed at a random position inside the test volume (please note that the receiving antenna should have no direct radiating path to the transmitting antenna and that it should also be cross polarized to the transmitting antenna). However, before creating the loaded chamber test, an application setting dialog (Figure 11) appears to select unloaded chamber calibration result table.

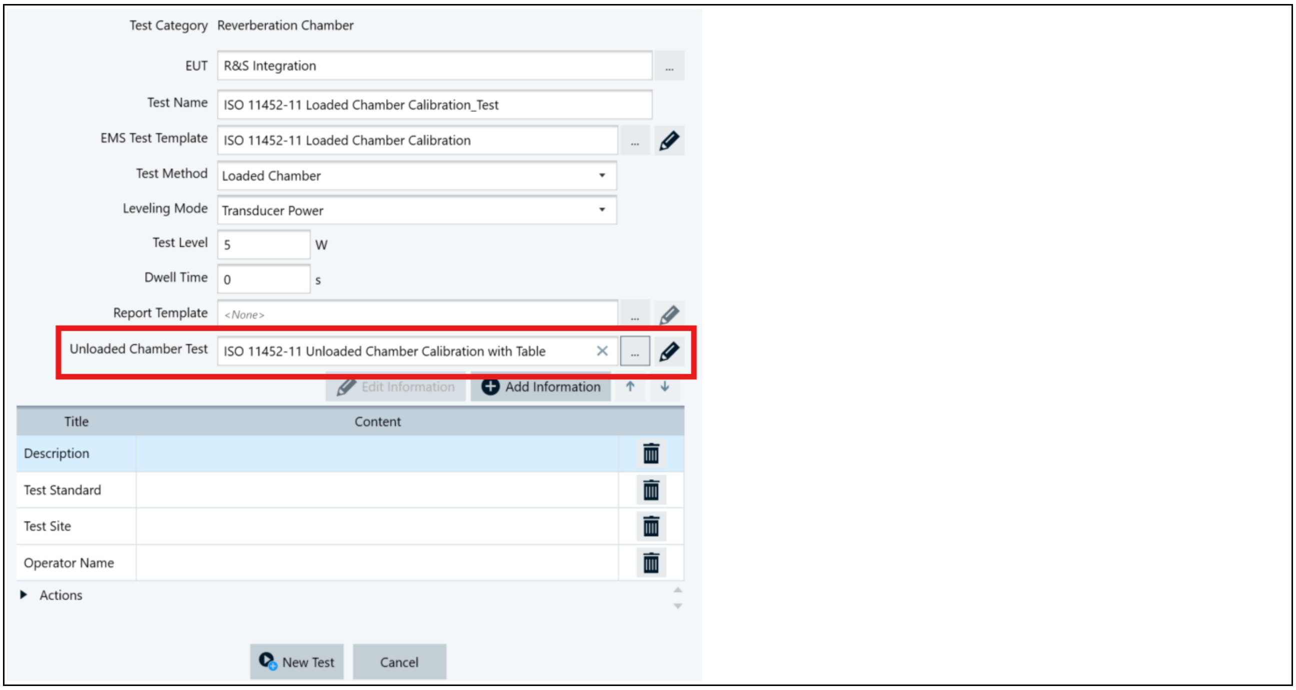


Figure 11 Test application setting view to select the unloaded chamber calibration result table of mode-tuned test.

Clicking “New Test” lets the user proceed with the test creation even without selecting an unloaded calibration chamber result table. This is particularly useful if chamber calibration results are available from the EMC32 software and R&S®ELEKTRA allows calibration results from EMC32 to be imported within test as explained later.

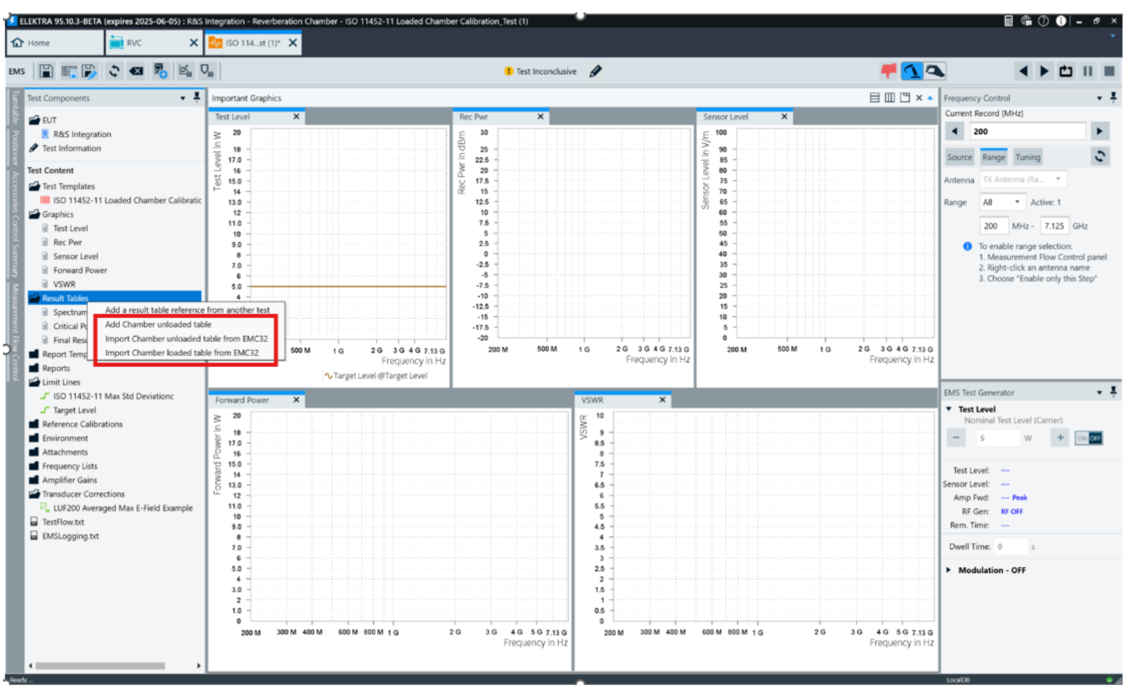


Figure 12 Selection of unloaded chamber calibration results inside the test view for mode-tuned test.

The unloaded calibration table can be selected within test within the test as shown in Figure 12. The menu allows the import of calibration results generated with EMC32 software to save time.

If the unloaded chamber test result table is not available, the test execution validation will not let the user proceed with the data evaluation phase of the test.

The data collection and evaluation phases of loaded chamber calibration are like those of the unloaded chamber calibration.

Figure 13 shows the various columns of the loaded test calibration results and Table 6 describes the unloaded chamber result columns based on [1].

ISO 11452-11 Loaded Chamber Table

Name	Rg	Freq...	CCF	Insertion Los...	Max Loa...	Standard Devi...	Standard Devi...	Standard Devi...	Standard Deviation XYZ	Input Level	Avg Rec Pwr	P Max Rec	Chamber Q(E)	Chamber Q(P)
Unit		MHz	dB	dB		dB	dB	dB	dB		dBm	dBm		
1	1	200.000	17.55	12.43	1.963039	2.68	2.44	3.14	2.69	5.309	19.70	26.80	110.828728	262.527191
2	1	211.200	18.32	14.23	1.741975	1.62	2.31	3.08	2.31	5.402	19.00	25.38	102.393494	258.886932
3	1	223.027	18.78	14.18	2.229825	2.61	2.72	2.42	2.56	5.329	18.49	26.41	139.925491	274.442230
4	1	235.517	18.14	13.71	1.597509	2.35	1.28	2.48	2.01	5.336	19.13	25.78	118.549149	374.119415
5	1	248.706	18.94	14.19	2.067920	2.71	2.31	1.78	2.22	5.294	18.30	26.70	179.163467	366.514008
6	1	262.633	20.30	16.09	1.937147	1.64	1.76	1.92	2.13	5.253	16.90	25.57	201.731461	315.493408
7	1	277.341	19.45	15.14	1.788355	2.54	3.10	1.65	2.89	5.280	17.78	25.35	208.417847	452.607880
8	1	292.872	19.53	15.05	1.657937	1.93	3.43	2.45	2.63	5.300	17.71	25.19	201.404739	522.496399
9	1	309.273	21.29	17.44	1.929630	1.74	2.23	1.03	1.79	5.283	15.94	21.50	180.873672	410.267334
10	1	326.592	21.22	17.45	1.577569	2.14	2.37	2.35	2.14	5.301	16.02	23.14	203.566010	491.057068
11	1	344.881	21.88	17.37	1.469472	3.12	1.99	3.08	2.59	5.324	15.38	21.35	224.548187	496.648865

Figure 13 Loaded chamber calibration result table of mode-tuned test.

Column Name	Description	Unit
Rg	Subrange number	None
Frequency	Frequency	Hz
CCF	Chamber correction factor (B.8)	dB
Insertion Loss	Insertion loss (B.9)	dB
Max loading	Calculated maximum loading factor (B.10)	None
Standard Deviation X, Y, Z	Standard deviation of the E-field for the x axis in dB (B.4) (B.5)	dB
Standard Deviation XYZ	Standard deviation of the E-field for the x axis in dB (B.6) (B.7)	dB
P_{input}	Input power into the transmitting antenna	dBm
P_{AveRec}	Average power received by the receiving antenna measured with the receiver device	dBm
P_{MaxREC}	Maximum power received by the receiving antenna measured with the receiver device	dBm
Chamber Q(E)	Estimated chamber Q factor using the chamber volume, the chamber wall permittivity, and the averaged field strength values	None
Chamber Q(P)	Calculated chamber Q factor using the chamber volume, the chamber wall permittivity, and the averaged power	None

Table 6 Loaded calibration result table column description of mode-tuned test.

Figure 14 shows the various columns for average normalized E-field and Table 7 describes the average normalized E-field table columns.

LUF200 Averaged Max E-Field ISO Table

Name	Frequency	Avg Norm Max E-Field	Insertion Loss Unloaded	Insertion Loss Loaded
Unit	MHz	(V/m)/√(W)	dB	dB
Interpolation	Logarithmic	Linear	Linear	Linear
1	200.000	35.742	49.50	12.43
2	422.400	35.585	49.48	14.23
3	446.054	35.849	49.57	14.18
4	471.033	36.020	49.46	13.71
5	497.411	36.367	49.44	14.19
6	525.266	36.141	49.47	16.09
7	554.681	35.552	49.57	15.14
8	585.743	35.244	49.55	15.05
9	618.545	36.189	49.57	17.44
10	653.184	35.901	49.49	17.45
11	689.762	35.981	49.48	17.37
12	728.389	35.406	49.57	17.70
13	769.178	36.144	49.48	17.18
14	812.252	36.302	49.39	17.46
15	857.738	35.996	49.47	20.48
16	905.772	35.767	49.46	20.10
17	956.495	35.674	49.53	19.84
18	1,000.000	35.704	49.45	19.38
19	1,000.000	35.758	49.59	19.05
20	1,056.000	35.150	49.49	21.14
21	1,115.136	35.235	49.52	20.26
22	1,177.584	36.038	49.49	20.54
23	1,200.000	35.140	49.47	20.53
24	1,200.000	35.800	49.50	21.45
25	1,262.400	35.995	49.54	21.19
26	1,328.045	35.723	49.46	21.84
27	1,397.103	36.035	49.46	24.02
28	1,469.752	36.222	49.49	23.72
29	1,546.180	35.417	49.51	23.64
30	1,626.581	35.574	49.52	25.73
31	1,711.163	36.189	49.54	24.75

Figure 14 Average normalized E-Field table after mode-tuned loaded calibration test.

Column Name	Description	Unit
Frequency	Frequency	Hz
Avg Norm Max E-field	Calculated average normalized maximum E-field (B.3) in V/m	V/m/SQR(W)
Insertion Loss (loaded)	Insertion loss (B.9)	dB

Table 7 Average normalized E-Field table column description after loaded chamber mode-tuned calibration.

Figure 15 shows the various evaluation graphics generated during the data evaluation phase. These graphics are stored in the evaluation graphics folder in the test content explorer.

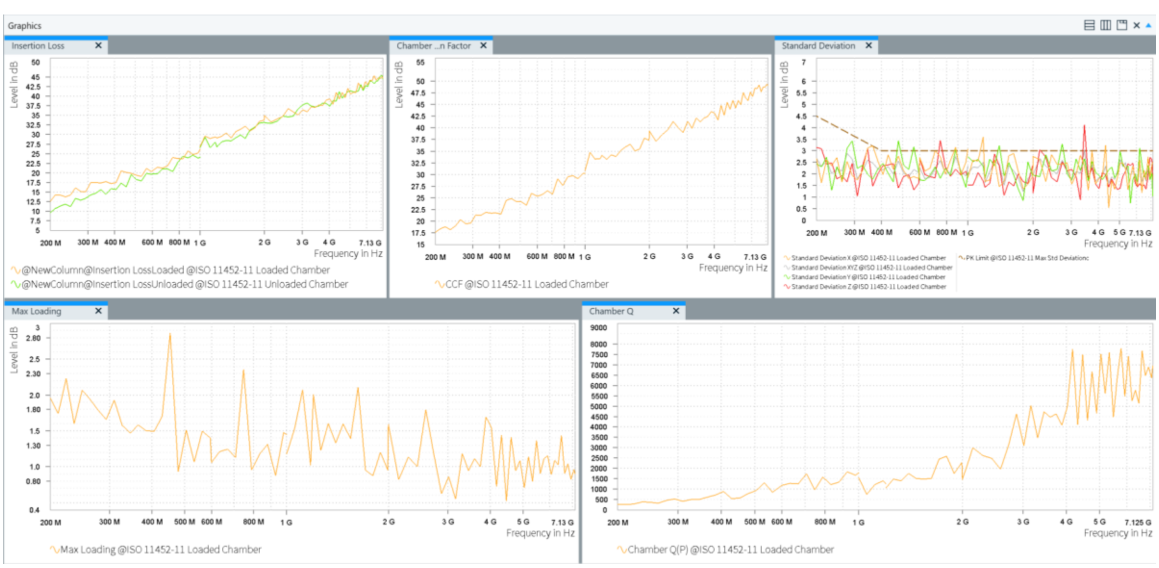


Figure 15 Loaded chamber evaluation graphics of mode-tuned test.

4.5.5 Mode-tuned EUT check test template configuration

The typical parameters of the EUT check that differ from unloaded/loaded test template configurations are shown in Table 8

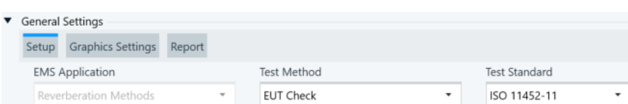
Parameter	Setting	Location in User Interface (UI)
Assess Method	EUT Check	General Setup => Setup
Input Evaluation Data	Min Required Pulse Width: 2.4 µs. Chamber Volume: 179.237m[3] (depends on chamber) Relative Permittivity: 8.8595 pF/m (depends on chamber)	Data Evaluation => Input Data
Output Evaluation Data	EUT Load Effect Table: EUT Load Effect Table Cahmber Loading Factor: Chamber Loading Factor	Data Evaluation => Output Data
Evaluation Graphics	Chamber Loading factor Chamber Calibration Factor Chamber Q Pulse Width	Data Evaluation => Evaluation Graphics

Table 8 Typical parameters of mode0tuned EUT Check test template

4.5.5.1 EUT check test template user interface previews

This section shows the UI for various EUT check parameters listed in Table 8.

Configuring the test method and test standard

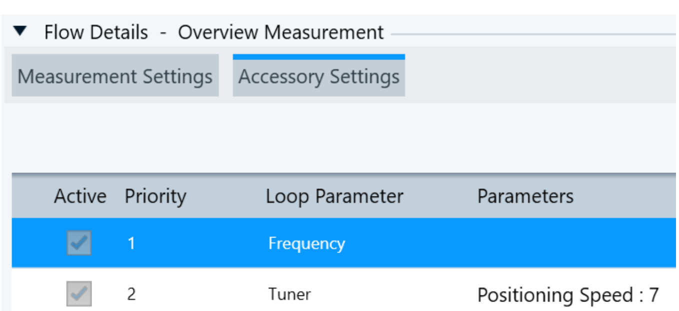


Configuring the measurement settings

The measurement settings are like those of the unloaded/loaded chamber test templates.

Configuring the accessory settings

Only the frequency and tuner loop are enabled for accessory settings.



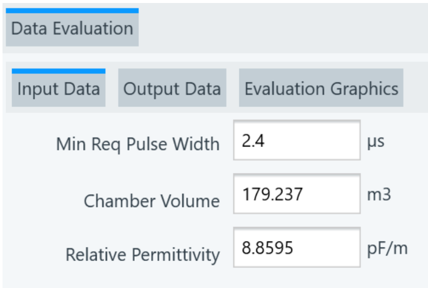
Configuring the subrange

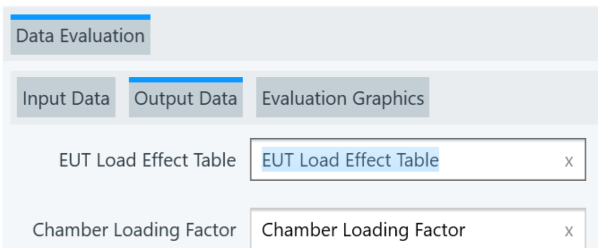
The subrange settings are like those of the unloaded/loaded chamber test templates.

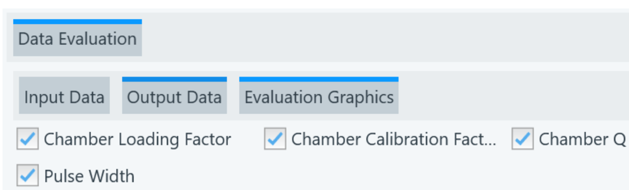
Configuring the system monitoring settings

The system monitoring settings are like those of the unloaded chamber test template.

Configuring the data evaluation







4.5.6 Mode-tuned EUT check test execution

The EUT check test creation and execution are the third step of the reverberation chamber calibration process. It is like the loaded chamber method but the field strength distribution in the test volume of the chamber is verified with the presence of the EUT. The receiving antenna is placed in a random position inside the test volume. Please note that the transmitting antenna should have no direct radiating path to the receiving antenna and that the transmitting and receiving antennas are cross polarized. However, before creating the EUT check test, a dialog for test application settings (Figure 16) appears for selecting the unloaded and loaded chamber calibration result tables.

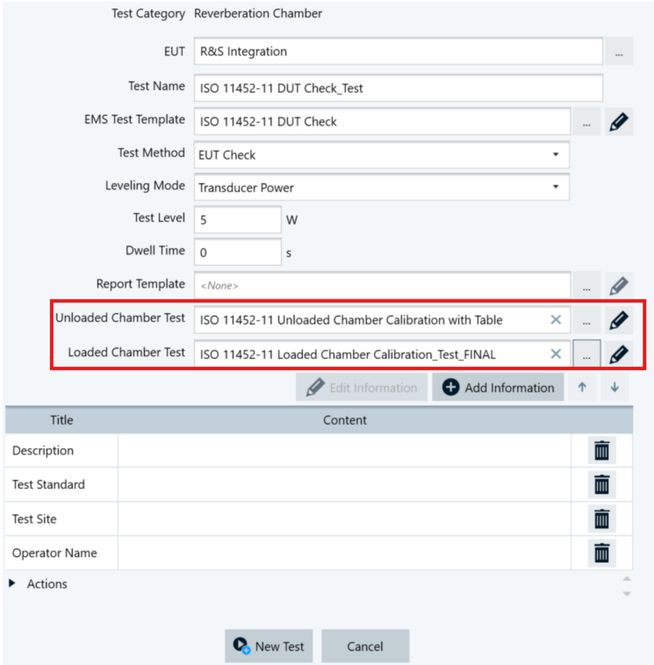


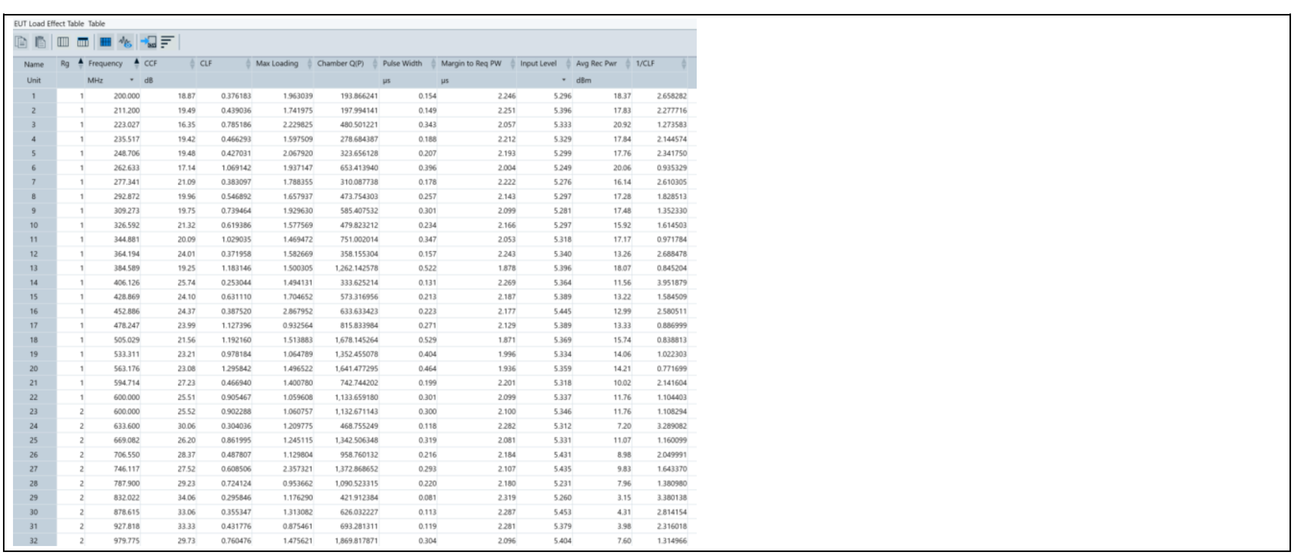
Figure 16 Test application setting view to select the mode-tuned unloaded chamber calibration and loaded chamber result tables.

A test can be created by clicking "New Test" even when no unloaded/loaded calibration chamber result tables are selected. They can be selected within the test as shown in Figure 12. The menu allows calibration results generated using EMC32 software to be imported and helps save time.

If the unloaded/loaded chamber test result tables are not available, the test execution validation will not allow users to proceed with the data evaluation phase of the test.

The data collection and evaluation phases of the loaded chamber calibration is like those of the unloaded/loaded chamber calibration but have differences in the measurement loops.

Figure 17 shows the various columns of the loaded test calibration results and Table 9 describes the EUT check chamber result columns based on [1]


EUT Load Effect Table Table

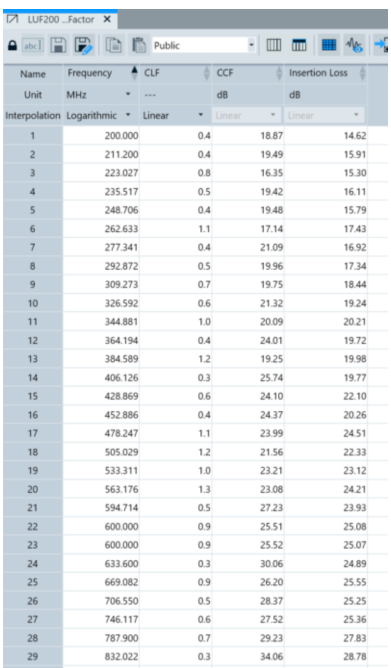
Name	Rg	Frequency	CCF	CLF	Max Loading	Chamber Q(P)	Pulse Width	Margin to Req PW	Input Level	Avg Rec Pwr	1/CLF
Unit		MHz	dB				µs	µs		dBm	
1	1	200.000	18.87	0.376183	1.963039	193.866241	0.154	2.246	5.296	18.37	2.658282
2	1	211.200	19.49	0.439036	1.741975	197.994141	0.149	2.251	5.396	17.83	2.277716
3	1	223.027	16.35	0.785186	2.229825	480.501221	0.343	2.057	5.333	20.92	1.273583
4	1	235.517	19.42	0.466293	1.597509	278.684387	0.188	2.212	5.329	17.84	2.144574
5	1	248.706	19.48	0.427031	2.067920	323.656128	0.207	2.193	5.299	17.76	2.341750
6	1	262.633	17.14	1.069142	1.937147	653.413940	0.396	2.004	5.249	20.06	0.935329
7	1	277.341	21.09	0.383097	1.788355	310.087738	0.178	2.222	5.276	16.14	2.610305
8	1	292.872	19.96	0.546892	1.657937	473.754303	0.257	2.143	5.297	17.28	1.828513
9	1	309.273	19.75	0.739464	1.929630	585.407532	0.301	2.099	5.281	17.48	1.352330
10	1	326.592	21.32	0.619386	1.577569	479.823212	0.234	2.166	5.297	15.92	1.614503
11	1	344.881	20.09	1.029035	1.469472	751.002014	0.347	2.053	5.318	17.17	0.971784
12	1	364.194	24.01	0.371958	1.582669	358.155304	0.157	2.243	5.340	13.26	2.688478
13	1	384.589	19.25	1.183146	1.500305	1,262.142578	0.522	1.878	5.396	18.07	0.845204
14	1	406.126	25.74	0.253044	1.494131	333.625214	0.131	2.269	5.364	11.56	3.951879
15	1	428.869	24.10	0.631110	1.704652	573.316956	0.213	2.187	5.389	13.22	1.584509
16	1	452.886	24.37	0.387520	2.867952	633.633423	0.223	2.177	5.445	12.99	2.580511
17	1	478.247	23.99	1.127396	0.932564	815.833984	0.271	2.129	5.389	13.33	0.886999
18	1	505.029	21.56	1.192160	1.513883	1,678.145264	0.529	1.871	5.369	15.74	0.838813
19	1	533.311	23.21	0.978184	1.064789	1,352.455078	0.404	1.996	5.334	14.06	1.022303
20	1	563.176	23.08	1.295842	1.496522	1,641.477295	0.464	1.936	5.359	14.21	0.771699
21	1	594.714	27.23	0.466940	1.400780	742.744202	0.199	2.201	5.318	10.02	2.141604
22	1	600.000	25.51	0.905467	1.059608	1,133.659180	0.301	2.099	5.337	11.76	1.104403
23	2	600.000	25.52	0.902288	1.060757	1,132.671143	0.300	2.100	5.346	11.76	1.108294
24	2	633.600	30.06	0.304036	1.209775	468.755249	0.118	2.282	5.312	7.20	3.289082
25	2	669.082	26.20	0.861995	1.245115	1,342.506348	0.319	2.081	5.331	11.07	1.160099
26	2	706.550	28.37	0.487807	1.129804	958.760132	0.216	2.184	5.431	8.98	2.049991
27	2	746.117	27.52	0.608506	2.357321	1,372.868652	0.293	2.107	5.435	9.83	1.643370
28	2	787.900	29.23	0.724124	0.953662	1,090.523315	0.220	2.180	5.231	7.96	1.380980
29	2	832.022	34.06	0.295846	1.176290	421.912384	0.081	2.319	5.260	3.15	3.380138
30	2	878.615	33.06	0.355347	1.313082	626.032227	0.113	2.287	5.453	4.31	2.814154
31	2	927.818	33.33	0.431776	0.875461	693.281311	0.119	2.281	5.379	3.98	2.316018
32	2	979.775	29.73	0.760476	1.475621	1,869.817871	0.304	2.096	5.404	7.60	1.314966

Figure 17 EUT Check result table of mode-tuned test.

Column Name	Description	Unit
Rg	Subrange number	None
Frequency	Frequency	Hz
CCF	Chamber correction factor (B.11)	dB
CLF	Chamber Loading Factor (B.12)	None
Max loading	Calculated maximum loading factor (B.10)	None
Chamber Q(P)	Calculated chamber Q factor (B.13)	None
Pulse Width	Calculated minimum pulse width (B.14)	Ms
Margin to Req PW	difference between the calculated minimum pulse width and the limit defined in the input parameters	µs
Input Level	Input power into the transmitting antenna	dBm
P_{AveRec}	Average power received by the receiving antenna measured with the receiver device	dBm
1/CLF	Inverse CLF for comparison to the Max. loading	None

Table 9 EUT Check result table column description of mode-tuned test.

Figure 18 shows the various columns of the chamber loading factor table and Table 10 describes the corresponding columns.



LUF200 ...Factor

Public

Name	Frequency	CLF	CCF	Insertion Loss
Unit	MHz	---	dB	dB
Interpolation	Logarithmic	Linear	Linear	Linear
1	200.000	0.4	18.87	14.62
2	211.200	0.4	19.49	15.91
3	223.027	0.8	16.35	15.30
4	235.517	0.5	19.42	16.11
5	248.706	0.4	19.48	15.79
6	262.633	1.1	17.14	17.43
7	277.341	0.4	21.09	16.92
8	292.872	0.5	19.96	17.34
9	309.273	0.7	19.75	18.44
10	326.592	0.6	21.32	19.24
11	344.881	1.0	20.09	20.21
12	364.194	0.4	24.01	19.72
13	384.589	1.2	19.25	19.98
14	406.126	0.3	25.74	19.77
15	428.869	0.6	24.10	22.10
16	452.886	0.4	24.37	20.26
17	478.247	1.1	23.99	24.51
18	505.029	1.2	21.56	22.33
19	533.311	1.0	23.21	23.12
20	563.176	1.3	23.08	24.21
21	594.714	0.5	27.23	23.93
22	600.000	0.9	25.51	25.08
23	600.000	0.9	25.52	25.07
24	633.600	0.3	30.06	24.89
25	669.082	0.9	26.20	25.55
26	706.550	0.5	28.37	25.25
27	746.117	0.6	27.52	25.36
28	787.900	0.7	29.23	27.83
29	832.022	0.3	34.06	28.78
30	878.615	0.4	33.06	28.57

Figure 18 Chamber loading factor table of mode-tuned test.

Column Name	Description	Unit
Frequency	Test Frequency	Hz
CLF	Chamber loading factor (B.12)	None
CCF	Chamber calibration factor (B.11)	dB
Insertion Loss	Insertion loss (B.9) of the unloaded chamber	dB

Table 10 Chamber loading factor table column description after mode tuned EUT Check

Figure 19 shows the various evaluation graphics generated during the data evaluation phase. These graphics are stored in the evaluation graphics folder in the test content explorer.

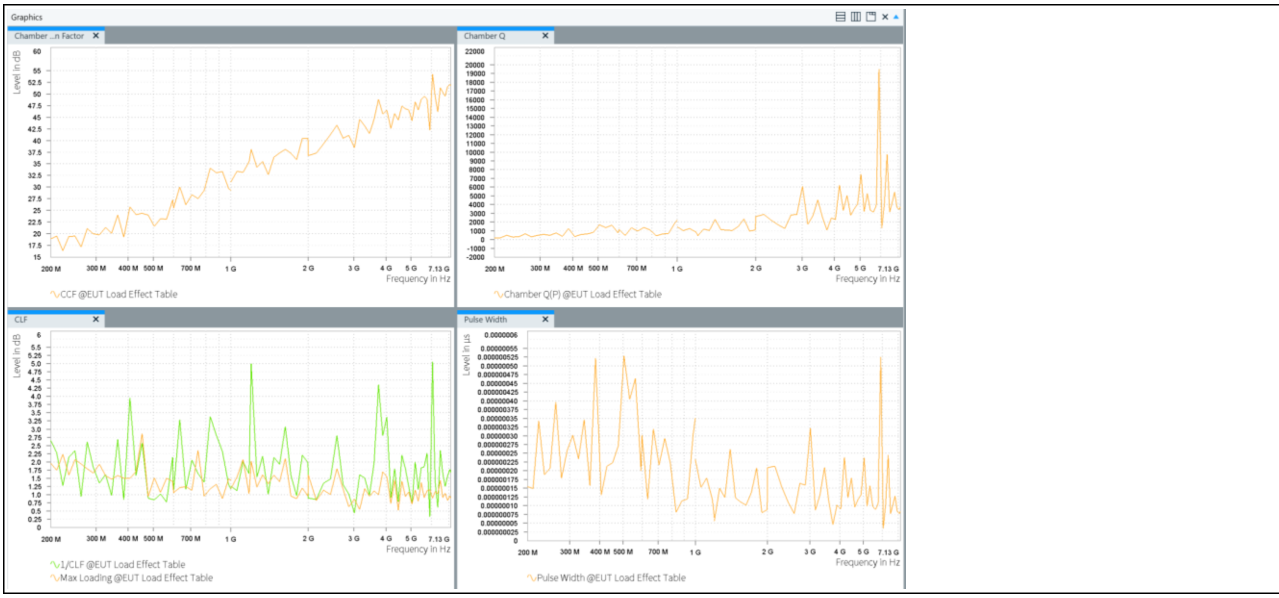


Figure 19 EUT Check Evaluation Graphics

4.5.7 Mode-tuned EUT test template configuration

The typical parameters for EUT qualification testing in the RVC are shown in Table 11.

Parameter	Setting	Location in User Interface (UI)
EMS Application	Reverberation Methods	General Setup => Setup
Test Method	EUT Qualification	General Setup => Setup
Test Standard	ISO 11452-11	General Setup => Setup
Level On	Power Relation	Measurement Settings => Leveling Mode
Power Control	Forward Power	Measurement Settings => Leveling Mode
Transducer Relation	pow(TESTNOMLEV(v/m) /RVCEFIELD, 2) / RVCCLF RVCEFILED is referenced from the avg norm max E-field table generated by unloaded chamber test RVCCLF is referenced from CLF table generated by EUT check	Measurement Settings => Calculate Transducer Power[W]
Avg Norm Max E-Field	LUF200 Averaged Max E-Field Example (updated from unloaded tests)	Measurement Settings => Avg Norm Max E-Field
Chamber Loading Factor	Chamber Loading Factor (updated from EUT Check test)	Measurement Settings => Chamber Loading Factor
Level Conservation for Modulation	CW Carrier = Modulation Carrier	Measurement Settings => Leveling Options
Power Limitation	Not Active	Measurement Settings => Power Level Limitation
Frequency Range	200 MHz – 7.125 GHz	Subrange Header
Frequency Steps	5.6%, LOG (200 MHz – 600 GHz) 5.6%, LOG (600 MHz – 1 GHz) 5.6%, LOG (1 GHz – 1.2 GHz) 5.2% LOG (1.2 GHz – 2 GHz) 1.45% DECLIN (2 GHz – 7.125 GHz)	Subrange Header
Test Level	100 V/m	Subrange => Test Level
Modulation	Off	UI not activated
Leveling Tolerance	0 dB – 0.4 dB	Subrange => Test Level

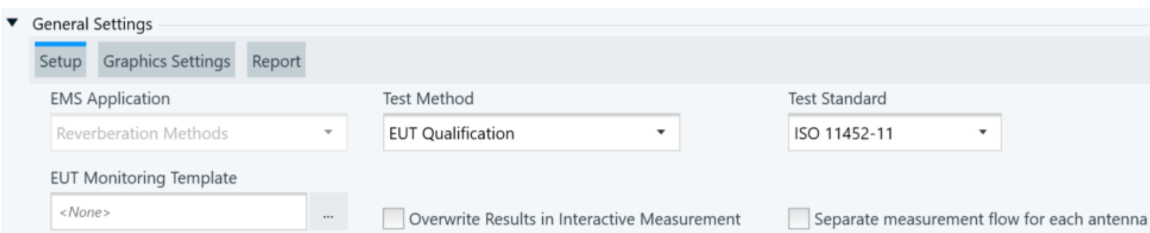
Parameter	Setting	Location in User Interface (UI)
Tuner	12	Subrange => Reverb Settings
Accessory Settings	Priority 1 => Frequency Priority 2 => Tuner	Accessory Settings
System Monitoring	Test Level Received Antenna Power Sensor Level Transducer Forward Power VSWR Amplifier Forward Power	System Monitoring

Table 11 Typical parameters of mode tuned EUT Qualification Test Template

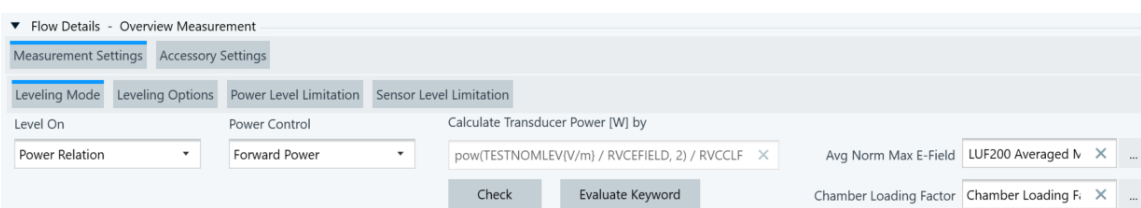
4.5.7.1 EUT test template user interface preview

This section shows the UI for various parameters listed in Table 11.

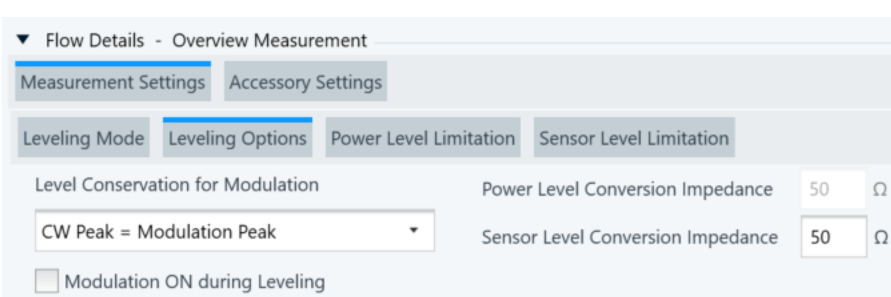
Configuring the test method and test standard



Configuring the measurement settings



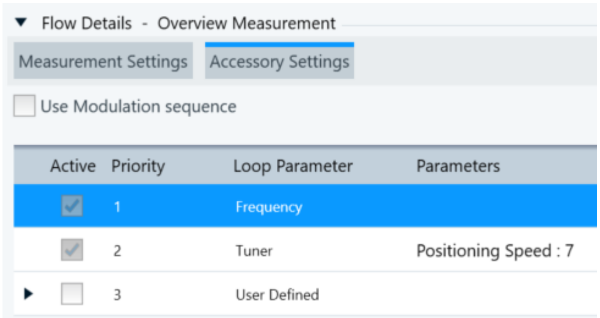
The formula to calculate the required forward power to generate the required electric field strength at each frequency is from [1]. However, the conversion factors are same as in [2] .



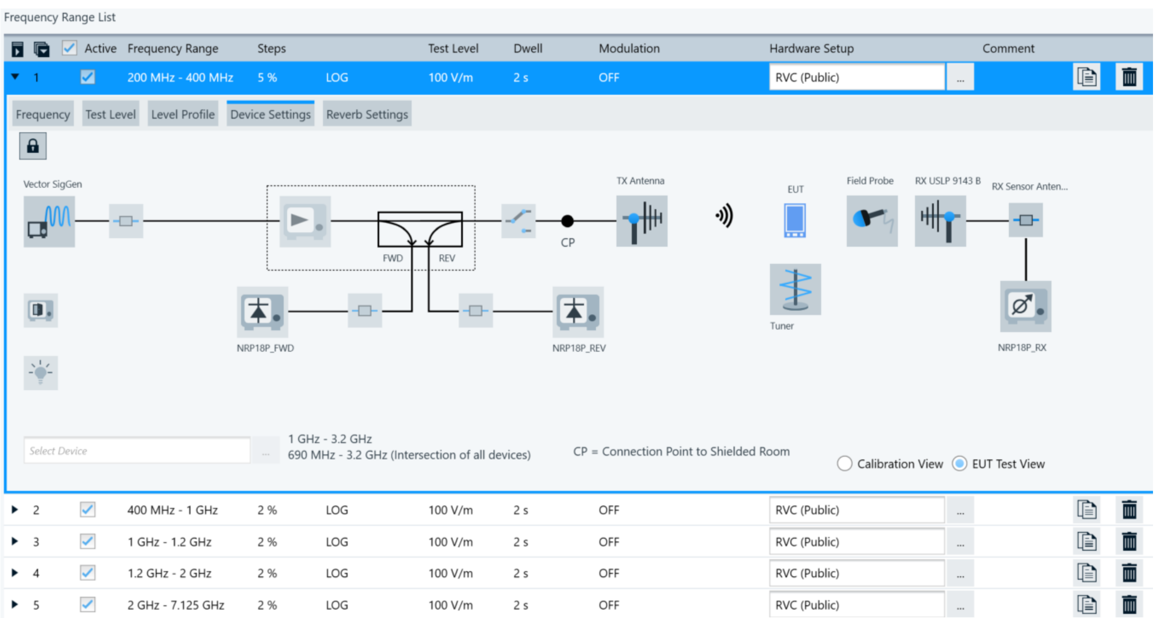
The level conservation needs to be CW carrier = modulation carrier for [1].

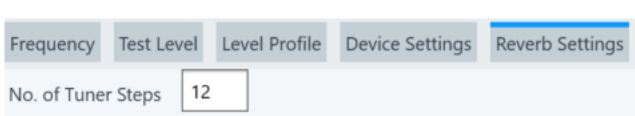
Configuring the accessory settings

For accessory settings, only the frequency and tuner loops are enabled.



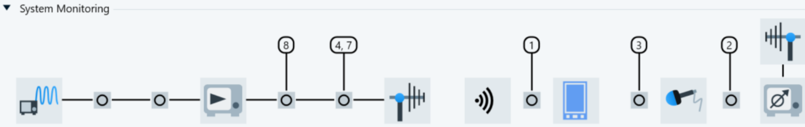
Configuring the subrange





Configuring the system monitoring settings

System Monitoring



No.	Active	Parameter	Unit	Y-Axis Range	Combine	LOG X-Axis	LOG Y-Axis	Display	Detector	Measurement Extension
1	✓	Test Level	W	0 ... 20	✓	✓	☐	✓	Carrier	-
2	✓	Received Antenna Power	dBm	-20 ... 30	✓	✓	☐	✓	Carrier	-
3	✓	Sensor Level	V/m	0 ... 100	✓	✓	☐	✓	Carrier	Measure all Field Sensor Axes
4	✓	Transducer Forward Power	W	0 ... 20	✓	✓	☐	✓	Peak	No Measurement
5	☐	Transducer Reverse Power	W	0 ... 100	✓	✓	☐	☐	Peak	-
6	☐	Transducer Net Power	W	0 ... 100	✓	✓	☐	☐	Peak	-
7	✓	VSWR	---	0 ... 10	✓	✓	☐	✓	None	-
8	✓	Amplifier Forward Power	W	0 ... 20	✓	✓	☐	✓	Peak	No Measurement
9	☐	Amplifier Reverse Power	W	0 ... 500	✓	✓	☐	☐	Peak	-
10	☐	Amplifier Saturation	dB	0 ... 10	✓	✓	☐	☐	None	-
11	☐	Amplifier Input	dBm	-50 ... 0	✓	✓	☐	☐	Carrier	-
12	☐	Generator Output	dBm	-50 ... 0	✓	✓	☐	☐	Carrier	-
16	☐	Insertion Loss	dB	0 ... 100	✓	✓	☐	☐	None	-

☐ Add Time Column to Overview Result Table

Combine Channels in Monitoring Graphics: Channel Unit

Configuring the data evaluation

The data evaluation settings are like those of any EUT tests done in an anechoic chamber

4.5.8 Mode-tuned EUT test execution

The EUT test creation and execution are like those of any EUT qualification/susceptibility tests performed in an anechoic chamber. Figure 20 shows the various columns of the EUT qualification test in an RVC.

Spectrum Overview Table

✓ Auto Scroll

Name	Rg	Frequency	Test Level	Rec Pwr	Sensor Level XYZ	Sensor Level X	Sensor Level Y	Sensor Level Z	Trd Fwd Pwr	VSWR	Amp Fwd Pwr	Modulation	Tuner Position	Comm
Unit		MHz	V/m	dBm	V/m	V/m	V/m	V/m	W	---	W			
1	1	200.000	102.25	17.00	36.20	22.74	24.98	12.98	21.756	2.01	25.733	OFF	12	
2	1	211.200	102.59	25.58	33.76	19.87	11.86	24.58	18.776	2.26	22.289	OFF	12	
3	1	223.027	103.72	29.13	37.56	31.26	17.97	10.52	10.739	2.35	12.882	OFF	12	
4	1	235.517	102.33	21.94	26.61	19.85	13.77	11.17	17.612	3.09	21.187	OFF	12	
5	1	248.706	102.49	21.44	42.58	33.44	9.17	24.72	19.304	1.40	23.385	OFF	12	
6	1	262.633	102.90	21.35	37.48	30.94	9.11	19.10	7.778	1.70	9.493	OFF	12	
7	1	277.341	103.52	3.81	63.87	42.22	40.51	25.63	21.981	1.85	26.931	OFF	12	
8	1	292.872	103.66	20.55	41.14	20.82	23.61	26.48	15.448	1.57	18.989	OFF	12	
9	1	309.273	103.66	13.95	33.34	29.76	13.98	5.55	11.434	1.20	14.162	OFF	12	
10	1	326.592	104.55	6.00	45.69	34.71	25.47	15.30	13.895	1.95	17.314	OFF	12	
11	1	344.881	103.51	16.78	24.58	20.78	12.09	5.11	8.203	1.66	10.275	OFF	12	
12	1	364.194	103.45	22.29	26.81	24.76	9.73	3.33	22.682	1.77	28.665	OFF	12	
13	1	384.589	102.80	11.34	25.59	16.19	13.05	14.91	7.045	2.03	8.910	OFF	12	
14	1	406.126	103.88	13.98	72.46	30.69	50.08	42.43	33.660	1.60	42.654	OFF	12	
15	1	428.869	103.16	17.14	21.06	13.39	3.07	15.96	13.262	1.22	17.051	OFF	12	
16	1	452.886	102.41	21.58	49.58	27.92	27.03	30.79	21.001	1.26	27.261	OFF	12	
17	1	478.247	102.74	10.93	29.71	14.89	23.32	10.84	7.178	1.34	9.352	OFF	12	
18	1	505.029	103.95	12.99	18.55	10.88	12.83	7.81	6.878	1.51	9.032	OFF	12	
19	1	533.311	103.58	10.45	43.95	29.43	20.75	25.20	8.474	1.38	11.177	OFF	12	
20	1	563.176	103.32	13.16	11.84	0.62	2.02	11.65	6.549	1.07	8.748	OFF	12	
21	1	594.714	101.55	16.66	48.18	26.97	13.54	37.56	17.516	1.01	23.529	OFF	12	
22	1	600.000	102.94	12.12	24.02	18.00	5.40	14.96	9.202	1.05	12.372	OFF	12	
23	2	600.000	103.37	12.18	24.11	18.01	5.54	15.04	9.279	1.05	12.475	OFF	12	
24	2	633.600	102.77	16.52	46.27	38.55	23.66	9.78	26.715	1.34	36.182	OFF	12	
25	2	669.082	102.42	13.11	31.25	15.50	4.13	26.82	9.423	1.51	12.855	OFF	12	
26	2	706.550	102.67	13.11	47.54	14.66	7.32	44.63	16.929	1.01	23.310	OFF	12	
27	2	746.117	102.52	10.80	21.28	9.97	10.80	15.40	13.528	1.04	18.789	OFF	12	
28	2	787.900	102.22	16.54	37.08	33.04	11.83	11.95	11.002	1.14	15.497	OFF	12	
29	2	832.022	104.15	10.93	47.58	4.04	34.53	32.49	28.030	1.20	39.786	OFF	12	
30	2	878.615	102.34	5.59	57.16	24.26	31.17	41.32	22.874	1.18	32.803	OFF	12	
31	2	927.818	102.65	8.76	45.35	11.22	22.12	37.97	19.122	1.24	27.627	OFF	12	
32	2	979.775	103.72	9.63	31.02	29.00	10.64	2.83	11.106	1.37	16.288	OFF	12	

Figure 20 Loop result table of EUT Qualification in mode-tuned test.

Figure 21 shows the various system monitoring graphics for the EUT qualification test in the mode-tuned RVC test.

Figure 21 System monitoring graphics of mode tuned EUT Qualification test.

Evaluation of EUT failure mode either by operator intervention or with EUT monitoring template is like those performed with the anechoic chamber and is not described in this application note.

5 Radiated immunity testing with closed-loop power control

The closed-loop power control is described in Annex G of 11451-5 [3] and uses eight field probes to measure electric field strength and calculate test levels and uniformity in real time as the field changes with mode stirring. The probe positions determine the test volume as shown in Figure 1. A significant benefit is that it does not require chamber calibration or EUT checks. Testing is done with the EUT in position. Chamber calibration, if needed, is done with mode-tuned method specified in section 4.

5.1 Closed-loop EUT test procedures

The field distribution is random, and the field can fluctuate at any point due to reflections and continuous mode-stirring. So, the power control loop for closed-loop testing based directly on field measurements might lead to unacceptably long levelling times or to the risk of over-testing if the stirring speed is not fast enough. So, the field probe system (Lumiloop LSProbe implementation) uses a statistical approach to the leveling process by acquiring field-strength distribution snapshots from eight probes and computing the cumulative distribution function (CDF). The R&S®ELEKTRA software then retrieves the field strength corresponding to a defined CDF level, such as 80%. If the field strength is within the target level ± tolerance, leveling is complete. If not, the forward power into the RVC is adjusted and the cycle repeats. Upon reaching the defined test level, the system triggers the dwell period, after which measurement procedures start. The mean forward power, mean reverse power, mean of the twenty-four maximum field components and four standard deviations required for a field uniformity evaluation are recorded.

5.2 Closed-loop hardware setup

In R&S®ELEKTRA, the radiated hardware setup for a reverberation chamber diagram type is used for the recommended hardware setup in a closed loop FRVC. Figure 22 shows the EUT view of a hardware setup with a single subrange. Since the closed-loop method does not require calibration, the hardware setup is fixed to EUT test view.

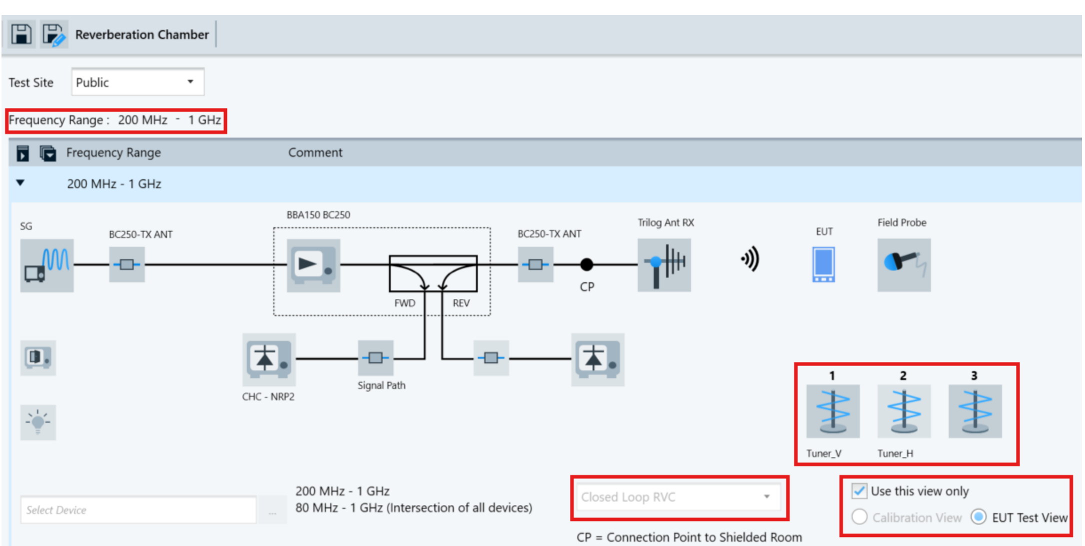


Figure 22 EUT view (200 MHz – 1 GHz) of a closed-loop test hardware setup.

The hardware is configured in closed-loop RVC mode that supports up to three independent tuners. Multiple tuners produce better mode density and field uniformity. Tuners should support continuous and endless stirring. Comtest and Frankonia tuners can be used as stirring devices in the compatible software for this application note (see 2) since they support continuous stirring. Future versions will support a wider range of tuners from various manufacturers, as well as a generic turntable for testing purposes. The setup in Figure 22 has two RVC tuners. See Table 1 for more details on the devices in the hardware setup. In the supported version of R&S®ELEKTRA, only the Lumiloop field probe system is supported for the closed loop. Also, the Lumiloop field probe system is configured very differently in the device list and used for the closed loop method.

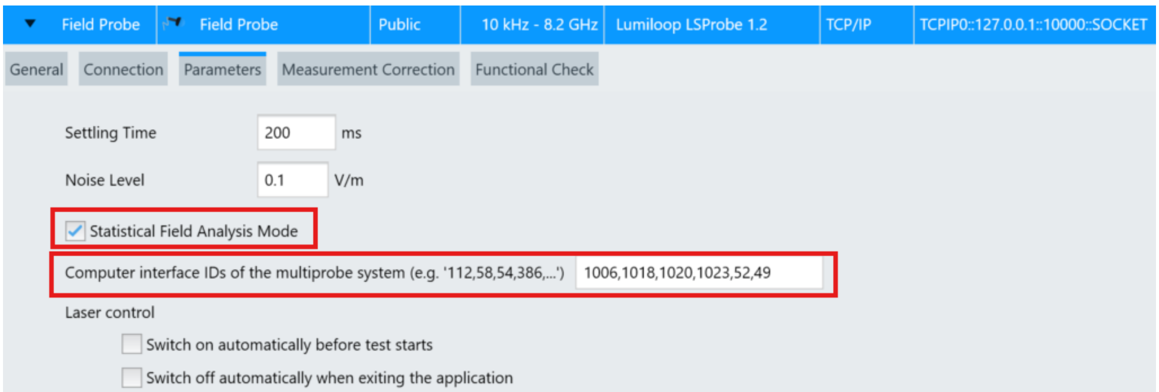


Figure 23 Lumi loop field probe parameter configuration for closed Loop test.

The Lumiloop field probe system should be configured in statistical field analysis mode, and eight field probes—identified by their computer interface IDs—should be assigned. No measurement correction is applied in this statistical mode, since it is managed internally by the field probe system. Using post-measurement result corrections in the statistical evaluation is not feasible as shown in Figure 24.

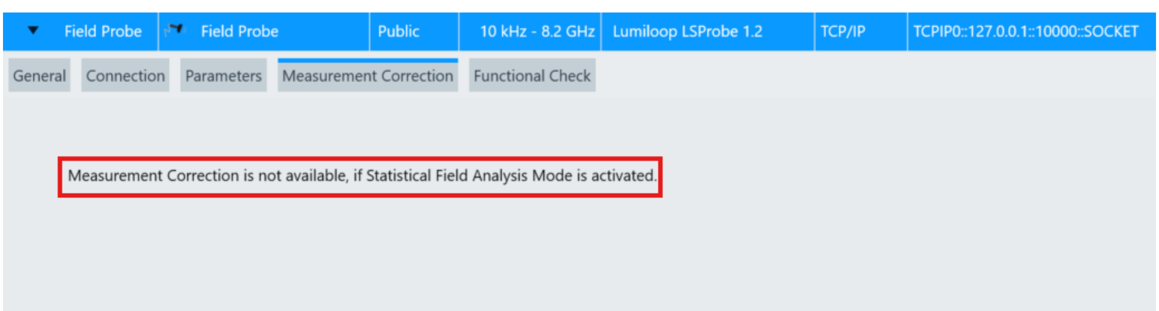


Figure 24 Lumiloop field probe measurement correction for closed loop test.

5.3 Closed-loop template configuration and test execution

The following sections describe the test template configuration for the EUT tests. The hardware setup must be created before configuring the test templates.

5.3.1 Closed-loop EUT test template configuration

The typical parameters for performing EUT qualification test in the RVC are shown in

Table 12.

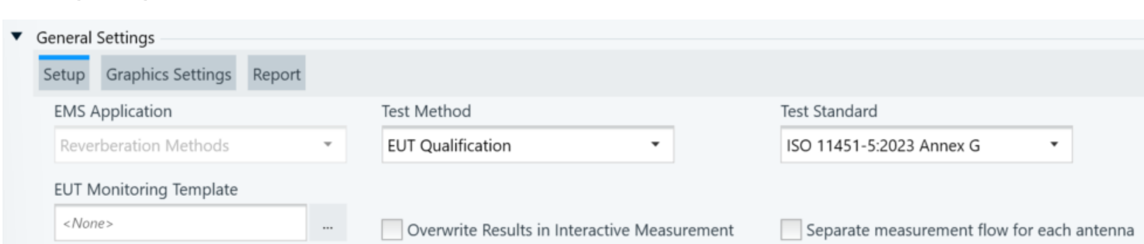
Parameter	Setting	Location in user interface (UI)
EMS Application	Reverberation Methods	General Setup => Setup
Test Method	EUT Qualification	General Setup => Setup
Test Standard	ISO 11451-5:2023 Annex G	General Setup => Setup
Level On	Sensor	Measurement Settings => Leveling Mode
Power Control	Forward 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
Sensor Limitation	Not Active	Measurement Settings => Sensor Level Limitation
Frequency Range	As per test requirements	Subrange Header
Frequency Steps	As per test requirements	Subrange Header
Test Level	As per test requirements	Subrange => Test Level
Modulation	Off	UI not activated
Leveling Tolerance	0 dB – 0.4 dB	Subrange => Test Level
Tuner	12	Subrange => Reverb Settings
Accessory Settings	Priority 1 => Frequency Priority 2 => User Defined	Accessory Settings
System Monitoring	Test Level E-Field Statistics Standard Deviation Transducer Forward Power VSWR Amplifier Forward Power	System Monitoring

Table 12 Typical parameters of EUT qualification test template in closed-loop test

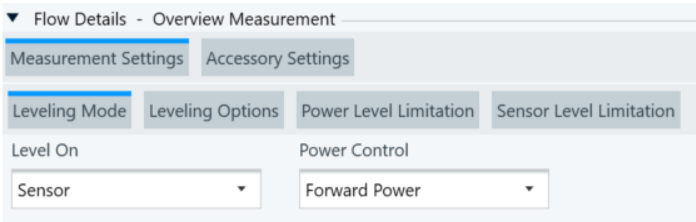
5.3.1.1 Closed-loop EUT test template UI previews

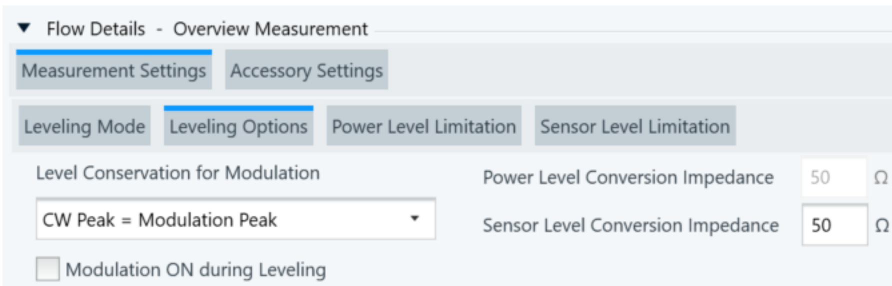
In this section, the UI for various EUT parameters listed in Table 12 are shown.

Configuring the test method and test standard



Configuring the measurement settings

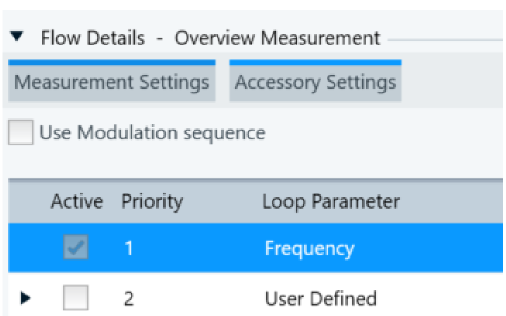




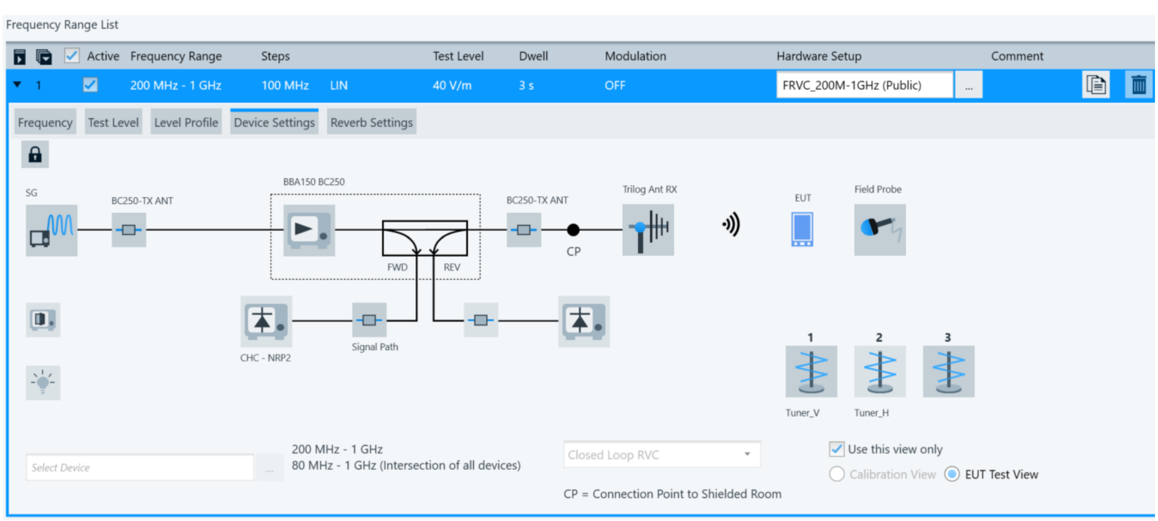
The level conservation needs to CW carrier = modulation carrier for [1].

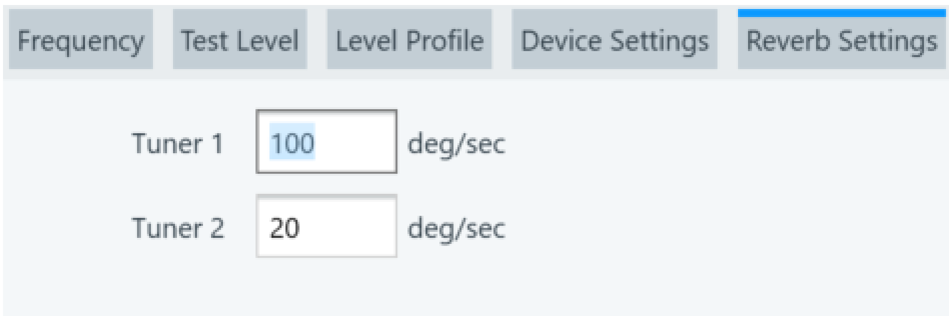
Configuring the accessory settings

Only the frequency is enabled for accessory settings.



Configuring the subrange





For every tuner, the tuner speed is configured in the reverb settings tab as shown in the above screenshot.

The Lumiloop field probe allows user to configure few parameters as shown in the screenshot below.

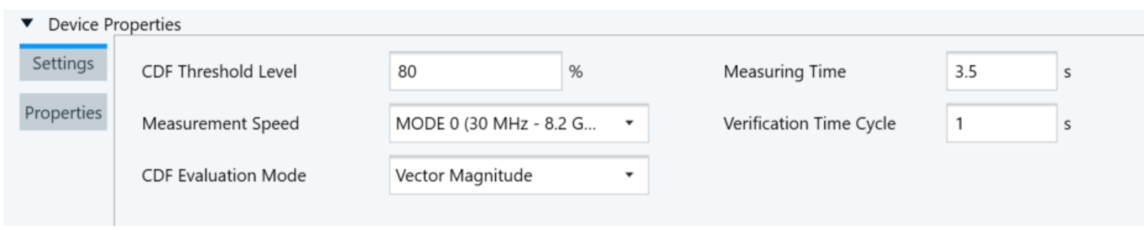
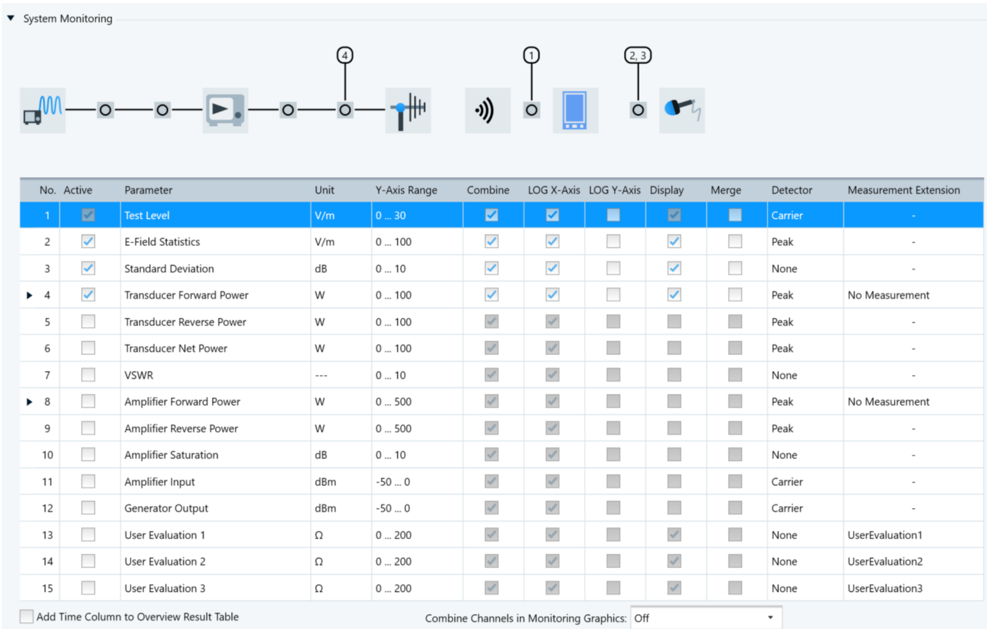


Table 13 presents the field probe configuration parameters along with typical values.

Parameter	Setting	Comments
CDF Threshold Level	80 %	Valid range (0 – 100). The value is used by the SW to level until the field strength meets the target.
Measurement Speed	Mode 0 (30 MHz – 8.2 GHz)	Data sampling rate of the field probe system
Measurement Time	3.5 s	Refers to the duration for which the field strength data is recorded before capturing the first data snapshot after a new forward power level is set
Verification Time Cycle	1 s	Interval within the dwell time after which the current field strength is checked
CDF Evaluation **Mode**	Axis Combined or Vector Magnitude	The option refers to two ways of evaluating field strength data from a multi-axis field probe. **Vector Magnitude**: A single scalar value representing the overall magnitude of the field (E_{Total}= $\sqrt{Ex^2 + Ey^2 + Ez^2}$) **Axis Combined:** Evaluating each axis separately & averaging $(E_x + E_y + E_z)/_3$

Table 13 Typical settings of field probe for closed loop method

Configuring the system monitoring settings



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

Add Time Column to Overview Result Table   Combine Channels in Monitoring Graphics: Off

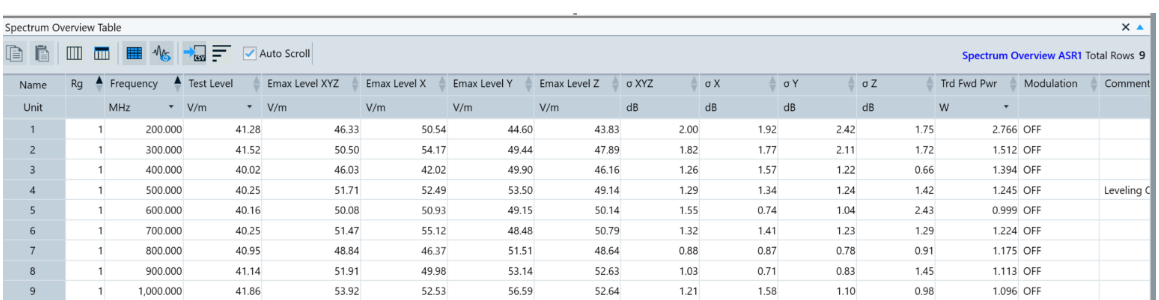
The E-field statistics channel represents the arithmetic mean of the maximum X, Y, Z and XYZ E-field values measured over the entire dwell time. The Standard Deviation channel represents the standard deviation in dB of the maximum X, Y, Z & XYZ E-field components measured during the test. The standard deviation values for E-field are only available in the overview results table of the test.

Configuring the data evaluation

The data evaluation settings are like any EUT tests done in an anechoic chamber

5.3.2 Closed-loop EUT test execution

The EUT test creation and execution are like any EUT qualification/susceptibility tests performed in an anechoic chamber. Figure 20 shows the various columns of the EUT Qualification test in closed loop test.



Name	Rg	Frequency	Test Level	Emax Level XYZ	Emax Level X	Emax Level Y	Emax Level Z	σ XYZ	σ X	σ Y	σ Z	Trd Fwd Pwr	Modulation	Comment
Unit		MHz	V/m	V/m	V/m	V/m	V/m	dB	dB	dB	dB	W		
1	1	200.000	41.28	46.33	50.54	44.60	43.83	2.00	1.92	2.42	1.75	2.766	OFF	
2	1	300.000	41.52	50.50	54.17	49.44	47.89	1.82	1.77	2.11	1.72	1.512	OFF	
3	1	400.000	40.02	46.03	42.02	49.90	46.16	1.26	1.57	1.22	0.66	1.394	OFF	
4	1	500.000	40.25	51.71	52.49	53.50	49.14	1.29	1.34	1.24	1.42	1.245	OFF	Leveling C
5	1	600.000	40.16	50.08	50.93	49.15	50.14	1.55	0.74	1.04	2.43	0.999	OFF	
6	1	700.000	40.25	51.47	55.12	48.48	50.79	1.32	1.41	1.23	1.29	1.224	OFF	
7	1	800.000	40.95	48.84	46.37	51.51	48.64	0.88	0.87	0.78	0.91	1.175	OFF	
8	1	900.000	41.14	51.91	49.98	53.14	52.63	1.03	0.71	0.83	1.45	1.113	OFF	
9	1	1,000.000	41.86	53.92	52.53	56.59	52.64	1.21	1.58	1.10	0.98	1.096	OFF	

Figure 25 Loop result table of EUT Qualification in closed loop test.

Figure 26 shows the various system monitoring graphics of the EUT qualification test in RVC.

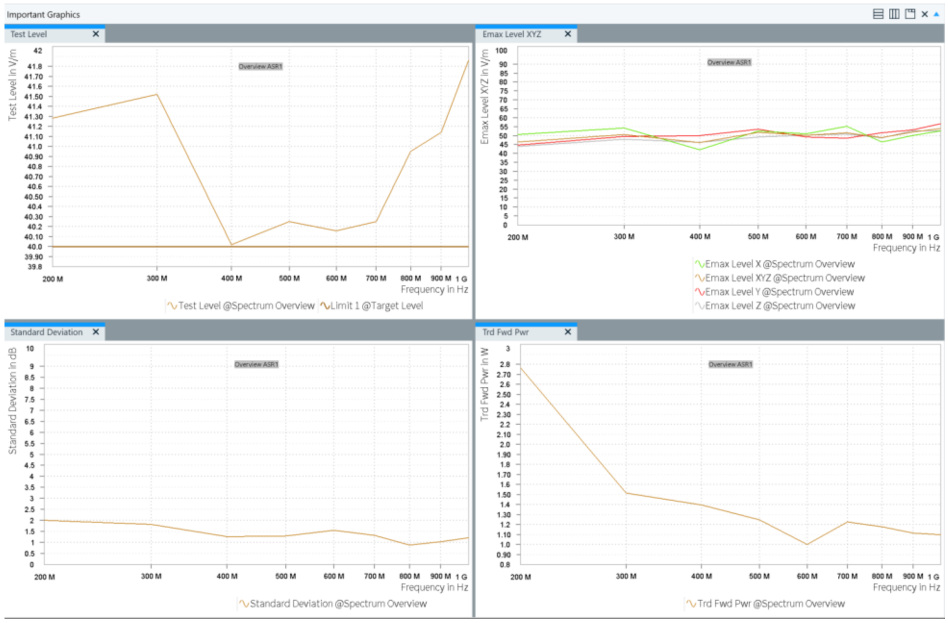


Figure 26 System monitoring graphics of EUT Qualification test in closed loop test.

Evaluation of EUT failure mode either by operator intervention or using EUT monitoring template is like those performed with Anechoic Chamber and is not described in this application note.

6 Comtest stirrer configuration

The Comtest stirrer assembly is driven by an Oriental controller. Figure 27 shows the settings dialog for Comtest stirrer with an Oriental controller.

The following settings are recommended for closed loop testing with R&S®ELEKTRA.

Parameter	Setting	Comments
User Unit	deg	Defines the units displayed with position- and velocity- related parameters
Distance per revolution	360	Distance per revolution in terms of user units
Gear A	1	The ratio Gear A/Gear B determines the velocity of the motor. For a ratio of 3:1, the motor has to rotate three times to cover the same distance
Gear B	1	See above
Motor Resolution	1000	Number of pulses per revolution

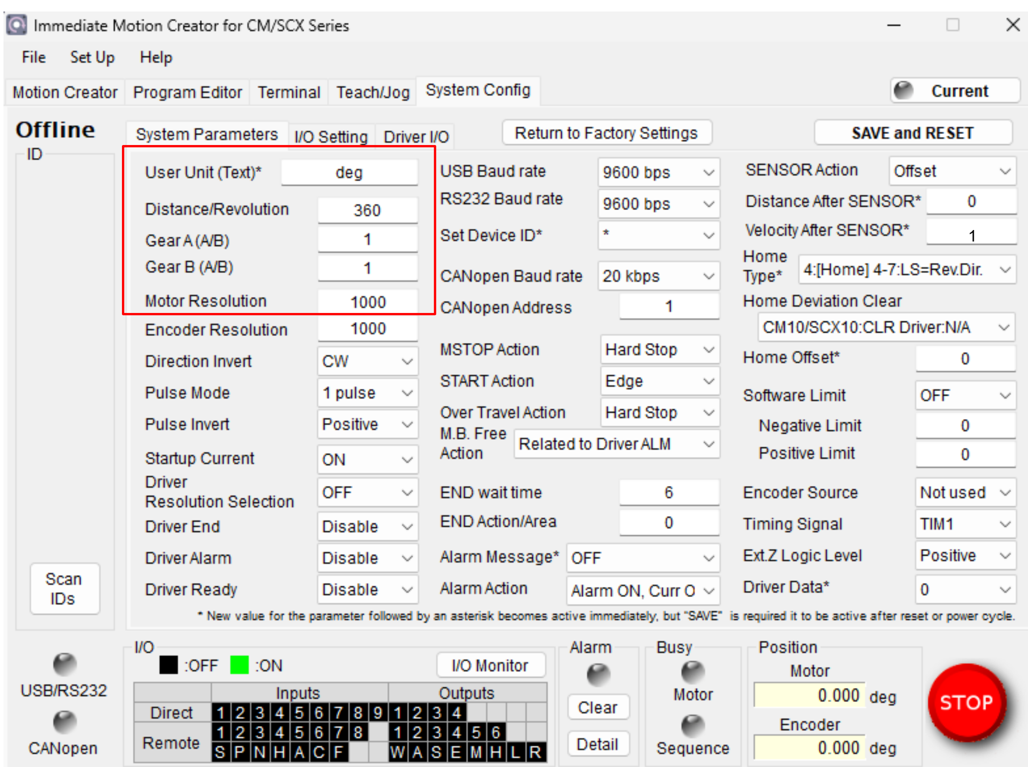


Figure 27 Comtest Stirrer Control Settings for closed loop test.

The user should consult the stirrer controller manual provided by the stirrer supplier.

7 Reference documents

[1] IEC 61000-4-21 Edition 2.0 2011-01 Electromagnetic compatibility (EMC) – Part 4-21: Testing and measurement techniques – Reverberation chamber test

[2] ISO 11542-11 Edition 2010-09-01 Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 11: Reverberation chamber

[3] ISO 11541-5 Edition xxx Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 5: Reverberation chamber

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