

EMC-CHAMBER VALIDATION MEASUREMENTS

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ABSTRACT

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This thesis explored the application of electromagnetic compatibility (EMC) standards EN55016-1-4 and EN 61000-4-3 to assist Verkotan in obtaining ISO 17025 accreditation status.

The objective was to perform three EMC measurements, Site Voltage Standing Wave Ratio (SVSWR), Normalized Site Attenuation (NSA), and Field Uniformity measurements which are used for validating EMC test sites.

The work involved reading and interpreting the relevant standards in depth, performing the measurements, and presenting the results for use in the accreditation process. The measurement results showed compliance with accreditation requirements. Comprehensive site-specific guides were developed for Verkotan to perform these measurements when necessary.

Additionally, the thesis explored other standards that use methodologies derived from EN 61000-4-3 and EN 55016-1-4, providing further context for their application in various EMC testing scenarios.

This thesis provided valuable support in establishing a solid foundation for EMC testing capabilities within the company.

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GLOSSARY

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|---------|---|
| CENELEC | European Committee for Electrotechnical Standardization – the organization responsible for standardization in electrotechnology in Europe. |
| CW | Continuous Wave – a waveform with a constant amplitude and frequency. |
| EMC | Electromagnetic Compatibility – the ability of electrical equipment to function properly in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. |
| EMI | Electromagnetic Interference – a disturbance generated by an external source that affects an electrical circuit through electromagnetic induction, electrostatic coupling, or conduction. |
| EN | European Norm – a standard adopted by CENELEC or another European standardization organization. |
| EUT | Equipment Under Test – the device being evaluated for compliance with applicable standards. |
| FAC | Fully Anechoic Chamber – a chamber used for electromagnetic compatibility testing with absorbing materials on all walls, the ceiling, and the floor. |
| IEC | International Electrotechnical Commission – a global organization that prepares and publishes international standards for electrical and electronic technologies. |
| ISO | International Organization for Standardization – an independent, non-governmental organization that develops and publishes international standards. |

| | |
|-------|--|
| NSA | Normalized Site Attenuation – a measure of a test site’s suitability for radiated emission measurements. |
| RF | Radio Frequency – the range of electromagnetic frequencies above audio and below infrared. |
| SAC | Semi-Anechoic Chamber – a chamber with radio frequency absorbers on walls and ceilings but a reflective ground plane. |
| SA | Site Attenuation – a measure of how much a test site attenuates signals. |
| SVSWR | Site Voltage Standing Wave Ratio – a metric used to evaluate the uniformity of an electromagnetic field in a test environment. |
| UFA | Uniform Field Area – the portion of a test site where the electromagnetic field meets the required uniformity criteria. |

1 INTRODUCTION

The validity and accuracy of Electromagnetic Compatibility (EMC) measurements are crucial in the certification process of electronic devices. EMC compliance testing requires precise and repeatable measurements that can consistently be reproduced in different EMC test facilities.

This paper was commissioned by Verkotan.

The three primary objectives of this paper are to analyze the chamber validation requirements for EMC chambers per EN55016-1-4 and EN61000-4-3, to implement these validation procedures in practice, and to develop a comprehensive guide for Verkotan to conduct future validation measurements.

This paper examines three important validation methods for EMC chambers: Normalized Site Attenuation (NSA), Site Voltage Standing Wave Ratio (SVSWR), and field uniformity measurements. These measurements ensure consistency and comparability between different EMC test sites.

2 OVERVIEW OF RELEVANT STANDARDS

To make sure that electromagnetic compatibility (EMC) measurements are accurate and consistent between different laboratories, several international standards guide and regulate the methodologies for assessments.

2.1 EN55016-1-4

The EN55016 standard outlines procedures for measuring electromagnetic interference and provides guidelines to ensure the uniformity of test sites. Published by the European Committee for Electrotechnical Standardization (CENELEC), the EN55016 series serves as a guide for EMC measurement instrumentation and methodologies. EN55016-1-4 addresses Normalized Site Attenuation (NSA) measurements for semi anechoic chambers and Site Voltage Standing Wave Ratio (SVSWR) for fully anechoic chambers. (EN55016-1-4 2019).

2.2 EN61000-4-3

The EN 61000-4-3 standard, part of the IEC 61000 series developed by the International Electrotechnical Commission, establishes procedures and limits for immunity testing of electrical and electronic equipment to radiated electromagnetic energy (EN 61000-4-3 2020, 1). This standard sets procedures to measure and maintain uniform exposure levels across the testing area, which is needed for making sure that equipment under test are tested with constant field strengths. In the field uniformity measurement, the relationship between the field strength and the forward power is determined and the forward power to generate required field strengths is found.

2.3 Other standards

In EN55032 Section 6.1 it states that the standard uses relevant basic requirements given in EN55016. EN55032 and EN55016 are examples of standards which are harmonized with each other. Harmonization is the act of making systems or laws the same or similar in different companies, countries, etc. (Cambridge Dictionary s.a.). One of the benefits of using harmonized standards is having a common assessment method for products i.e. same chamber, same signal receiver, antennas, etc. (European Commission s.a.).

Some other examples of standards that use methods from EN55016 and EN61000-4-3 are EN 301 489-1 where in section 8.2 it defines the test method for enclosure port, i.e. physical boundary of the equipment, radiated emissions to be in accordance with EN55032 and in section 9.2 it defines the test method for enclosure port radiated immunity to be in accordance with EN61000-4-3. EN 301 489-1 is used for radio equipment and services. (ETSI EN 301 489-1 2019). EN61000-6-3 provides emission measurement methods and limits for equipment used in residential, commercial and light-industrial environments. In section 11 it defines test details, where methods from EN55016 are used. (EN 61000-6-3 2021).

3 MEASUREMENT TECHNIQUES

3.1 Normalized Site Attenuation

This section outlines the NSA measurement procedure, as specified in EN55016-1-4, which is used for validating the performance of semi-anechoic chambers (SACs) from 30 MHz to 1 GHz. It provides a measure of uniformity of the validated test volume using a comparison between ideal (theoretical) given in EN55016-1-4 table 2 and measured site attenuation between the transmit antenna and the receive antenna. The NSA method with broadband antennas is used.

3.1.1 Measurement Equipment

The setup includes a calibrated signal generator, broadband antennas with known gains, and an EMI receiver. (EN55016-1-4 2019, 53).

3.1.2 Measurement Chamber

EN55016-1-4, Section 6.3.1 allows the use of semi-anechoic chambers for emission measurements. It is a shielded enclosure where all walls and the ceiling are covered with RF absorbing material as shown in Figure 1. It isolates the receive antenna from ambient RF. (EN55016-1-4 2019, 19).



Figure 1. An example of a semi-anechoic chamber.

3.1.3 Measurement Setup

The test volume can be defined by the largest equipment under test to be rotated 360°, for example, by the turntable installed in the measurement chamber. The antennas will be placed around the test volume as shown in Figure 2. The antennas will face each other and have a constant distance during the whole measurement in all positions. (EN55016-1-4 2019, 54).

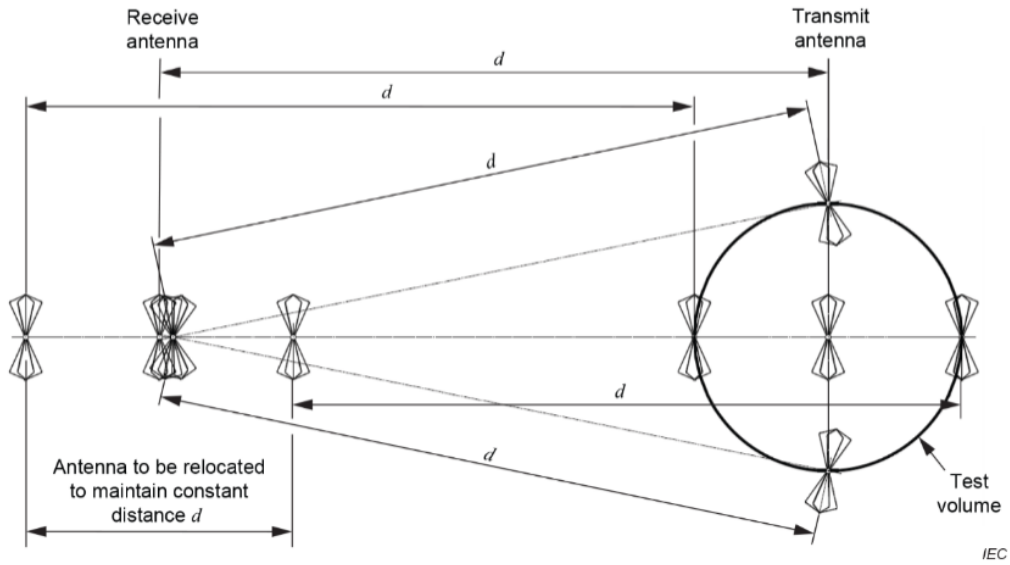


Figure 2. NSA measurement setup, horizontal. For vertical the setup is the same, but the antenna polarization shown is different. (EN55016-1-4 2019, 56)

The signal generator can be connected to the transmit antenna and the EMI receiver can be connected to the receive antenna with any suitable length of cable as shown in Figure 3. (EN55016-1-4 2019, 54).

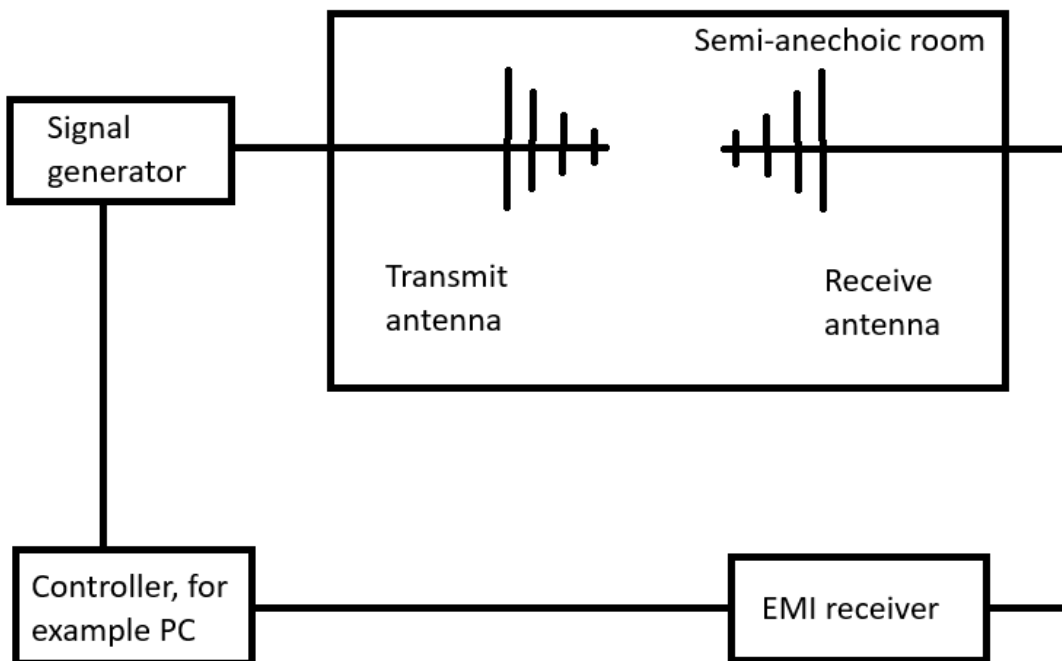


Figure 3. NSA measurement setup diagram

3.1.4 Measurement Procedure

The NSA measurement can be done by swept frequency method where by adjusting a signal generator to produce a clear signal above noise levels and sweeping the frequency range with a spectrum analyzer while varying the receive antenna height from h_1 to h_2 , where h_1 and h_2 are defined in EN55016-1-4 Table 2, recording the maximum voltage (V_{SITE}) and measuring the direct signal (V_{DIRECT}) by directly connecting the transmit and receive cables. Then data is analyzed according to 3.1.5. (EN55016-1-4 2019, 54). The signal strength is kept constant during the measurement (EN55016-1-4 2019, 43).

3.1.5 Data Analysis and validation

To calculate the site attenuation (SA) deviation, according to EN55016-1-4 Section 7.3.1, from the theoretical values given in EN55016-1-4 Table 2 the equation:

$$\Delta A_s = V_{DIRECT} - V_{SITE} - F_{aT} - F_{aR} - A_N$$

is used, where

ΔA_s is the SA deviation;

F_{aT} is the transmit antenna factor;

F_{aR} is the receive antenna factor;

A_N is the theoretical NSA, according to EN55016-1-4, Table 2.

Plot the measured A_s and theoretical NSA as a function of frequency to verify compliance with the ± 4 dB acceptance criterion.

3.2 Site Voltage Standing Wave Ratio

This section outlines the SVSWR measurement procedure, as specified in EN55016-1-4, which is used for validating the performance of fully anechoic chambers (FACs). It provides a measure of reflections and standing waves within the test volume by evaluating field variations as the receiving antenna is moved along a horizontal line at a fixed height. The measurement compares the maximum and minimum signal levels received to assess the impact of reflections from the chamber walls, floor, and other surfaces that could affect measurement accuracy. (EN55016-1-4 2019, 70).

3.2.1 Measurement Equipment

The setup includes a calibrated signal generator, antennas with known gains, and an EMI receiver. (EN55016-1-4 2019, 79)

3.2.2 Measurement Chamber

For emission measurements EN55016-1-4, Section 7 mandates reflection-free conditions. These conditions can be met with a fully anechoic room with the use of absorbing materials. (EN55016-1-4 2019, 69). It is a shielded enclosure where all internal surfaces are covered with RF absorbing material. It isolates the receive antenna from ambient RF. (EN55016-1-4 2019, 17). If the measurement chamber is not designed to produce reflection-free conditions, for example a semi-anechoic room, absorbers must be placed to cover part of the floor as shown in Figure 4. (EN55016-1-4 2019, 69).

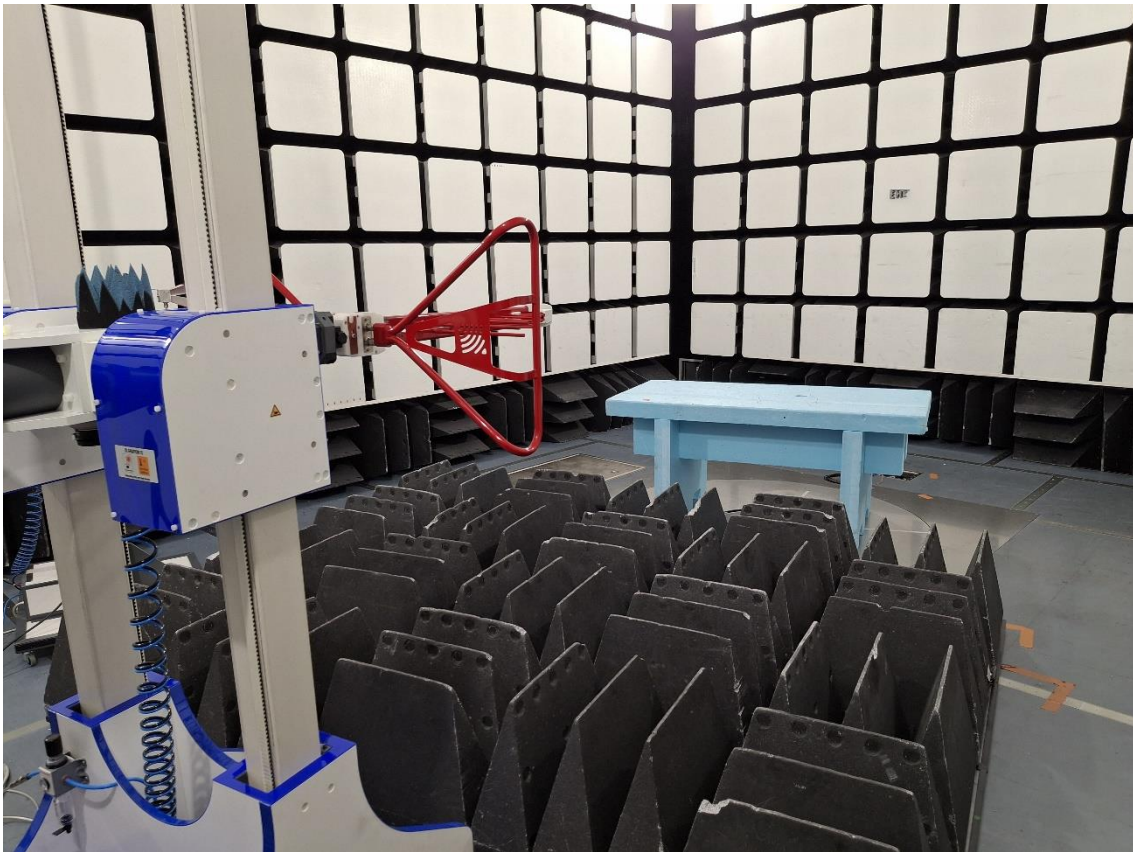


Figure 4. An example of a semi-anechoic chamber with absorbers placed on the floor to create reflection free conditions.

3.2.3 Measurement Setup

The receive antenna must be placed around the test volume as shown in Figure 5. The transmit antenna is pointed at the receive antenna during the whole measurement in all positions. The receive antenna is kept at a constant distance d from the boundary of the test volume. (EN55016-1-4 2019, 74) The transmit antenna is moved away from the receive antenna in the following steps: 1) $X5 = X6 + 2$ cm. 2) $X4 = X6 + 10$ cm. 3) $X3 = X6 + 18$ cm. 4) $X2 = X6 + 30$ cm. 5) $X5 = X6 + 40$ cm. $X6$ is used as a reference point. Right (R) positions can be found by determining the right extent of the volume (R1). Left (L) positions can be found by determining the left extent of the volume (L1). Front (F) positions can be found by determining the front extent of the volume (F6). And lastly the center (C) positions can be found by determining the center of the volume (C6). (EN55016-1-4 2019, 75).

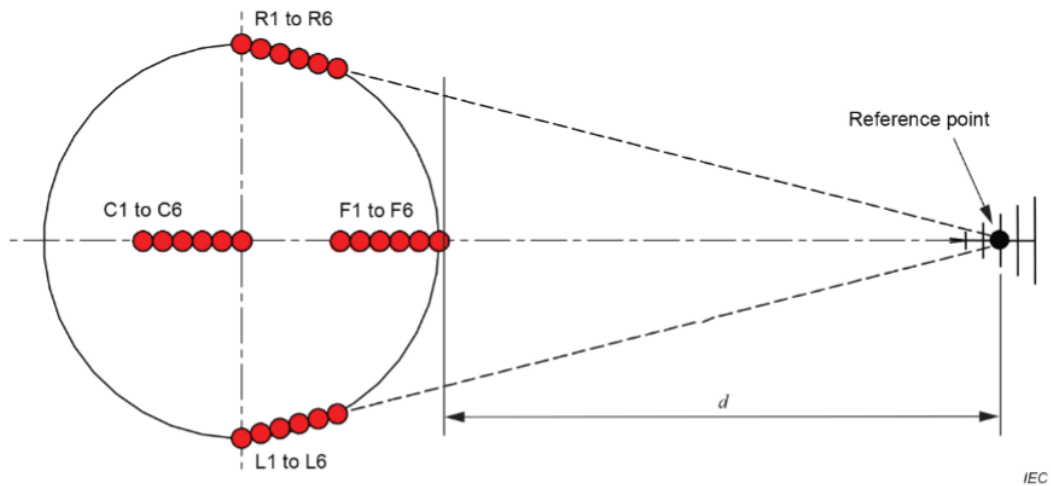


Figure 5. SVSWR measurement setup where the red dots represent the positions that the transmit antenna shall be moved along. (EN55016-1-4 2019, 74)

When the top of the test volume (h_2) is more than 0,5 m away from h_1 (the middle of the test volume or 1m above the bottom of the test volume) one additional measurement must be done in the front position at the top of the test volume. The size of the test volume is determined by the EUT as stated in 3.1.3 but the lowest allowed point of the test volume is determined by the height of the absorbers shown in Figure 6. Since the maximum allowed portion of the volume that is obstructed by absorbers (h_a) can only be 30 cm when using, for example 40 cm high absorbers, the lowest point of the volume is 10 cm above the floor. (EN55016-1-4 2019, 76).

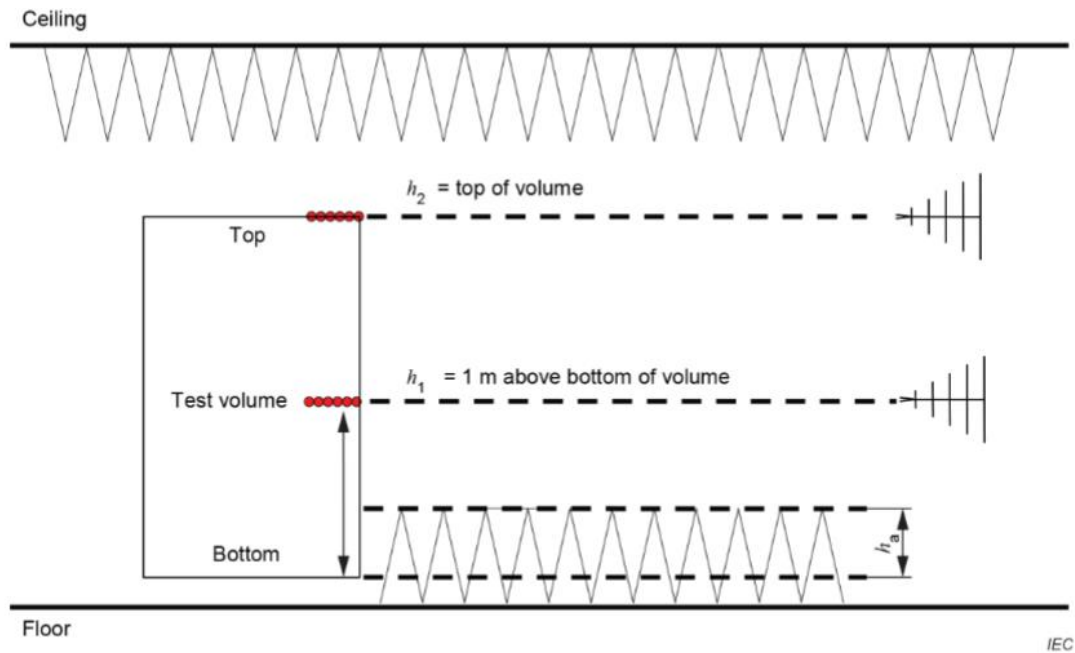


Figure 6. SVSWR additional measurement position. The top and the bottom of the test volume is shown. (EN55016-1-4 2019, 76).

The signal generator can be connected to the transmit antenna and the EMI receiver can be connected to the receive antenna with any suitable length of cable as shown in Figure 7. Since the SVSWR calculation, described in 3.2.5, does not take into account the cable attenuation the length of the cable does not matter it only considers the ratio of the received signal strengths at different positions. (EN55016-1-4 2019, 70)

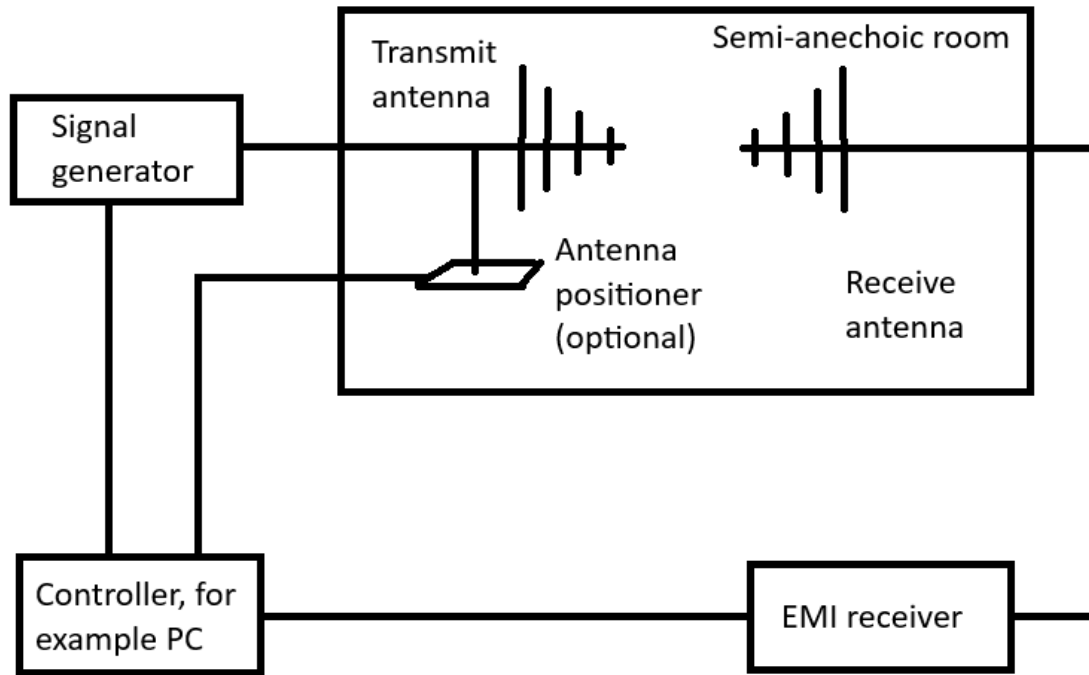


Figure 7. SVSWR measurement setup diagram.

3.2.4 Measurement Procedure

The method involves positioning the transmit antenna at reference position 6, height 1, in horizontal polarization, and setting the receive antenna at a test distance. The received signal strength is checked to be at least 20 dB above ambient noise, then measured at each frequency using either swept or stepped frequency increments. After measuring, the signal is normalized to the reference distance. The SVSWR is calculated by comparing the maximum and minimum received signals at each position, and the results are checked against the 6 dB acceptance criterion as shown in 3.2.5. The process is repeated for vertical polarization and for additional position if necessary with the receive antenna height matching the transmit antenna height. (EN55016-1-4 2019, 79, 80).

3.2.5 Data Analysis and validation

To calculate the SVSWR, according to EN55016-1-4 Section 7.3.1, from the measured values:

$$S_{VSWR,dB} = 20 \lg \left(\frac{V_{max}}{V_{min}} \right) = 20 \lg \left(\frac{E_{max}}{E_{min}} \right) = V_{max,dB} - V_{min,dB} = E_{max,dB} - E_{min,dB}$$

is used, where

$V_{max,dB}$ and $V_{min,dB}$

$E_{max,dB}$ and $E_{min,dB}$

Plot the calculated ratio as a function of frequency to verify compliance with the 6 dB acceptance criterion.

3.3 Field Uniformity

This section of the paper shall explain the field uniformity measurements and its requirements as they are described in the standard EN61000-4-3.

3.3.1 Uniform Field Area

In the standard the area where devices are exposed to electromagnetic fields is called the uniform field area (UFA). In the UFA the field variations remain within 6 dB along a vertical plane.

The minimum distance from the antenna to EUT is 1 meter and the usual distance is 3 meters but any distance over 1 meter can be used. The position of the antennas, absorbers, cables, etc. should be recorded because even small changes in the setup might affect the field, especially at high frequencies. (EN 61000-4-3 2020, 20).

For the measurement the size of the UFA needs to be determined. The lower edge of a UFA can be at any height. The shape of the UFA must remain rectangular. The distance between UFA grid points must be 0,5 m as shown in Figure 8.

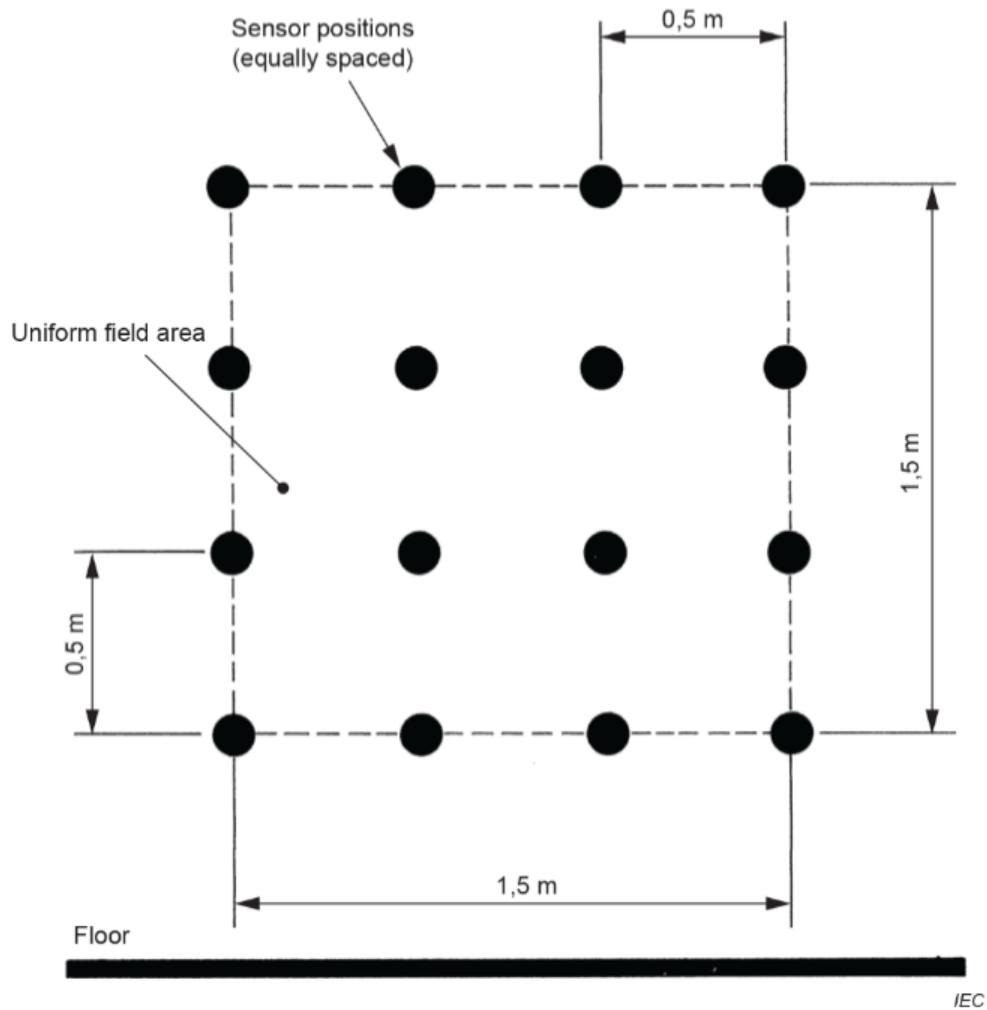


Figure 8. Dimensions of a sixteen-point UFA (EN 61000-4-3 2020, 20).

The minimum size of the UFA is 0,5 m x 0,5 m. If the minimum size is chosen a fifth dot must be added inside the 0, 5 m x 0,5 m grid as shown in Figure 9. A smaller UFA may be necessary when the antenna distance is decreased for higher disturbance levels. After defining the UFA grid, measurements are taken at each grid point using an isotropic field probe. (EN 61000-4-3 2020, 20).

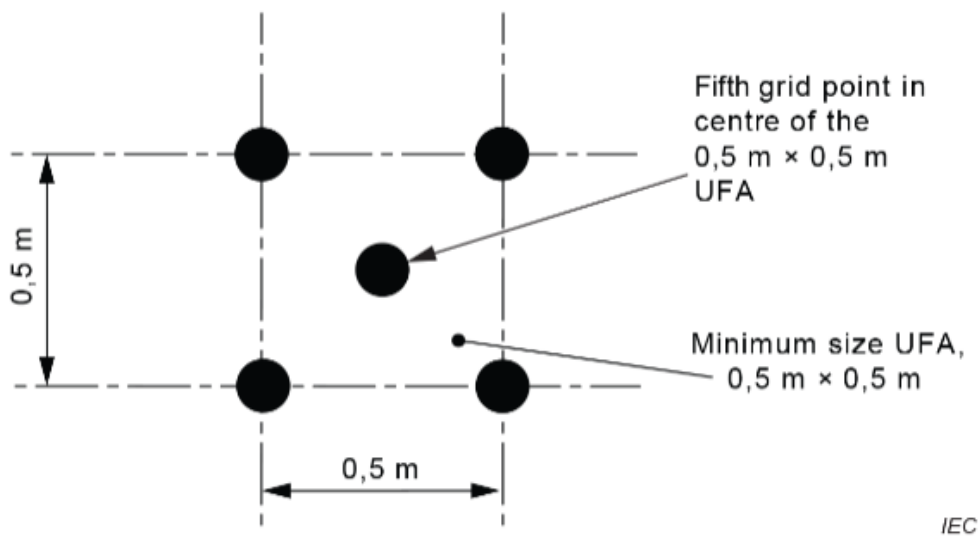


Figure 9. Dimensions of a minimum size five-point UFA (EN 61000-4-3 2020, 21).

3.3.2 Measurement Equipment

The standard EN61000-4-3 recommends certain types of equipment to be used in immunity testing, including anechoic chamber, RF signal generators, power amplifiers, field generating antennas, isotropic field sensors, and any linearly polarized antenna, all covering the required frequency band. (EN 61000-4-3 2020, 17)

3.3.3 Measurement Chamber

To comply with national and international laws prohibiting interference with radio communications, a shielded enclosure must be used because of the field strengths generated during the tests (EN 61000-4-3 2020, 17). For example, according to the Finnish penal code gross interference in communications is a punishable offence with a maximum sentence of up to 5 years of imprisonment. (Finnish Penal Code, chapter 36, section 6).

An anechoic chamber should be lined with absorbers and be large enough to accommodate the EUT while allowing adequate control over the field strengths. It is stated that a shielded enclosure should be used to house the field generating

and the monitoring equipment. (EN 61000-4-3 2020, 17). Since the text uses the word "should", it should be noted that it is only a recommendation and not a requirement (IEC Academy 2020). Figure 10 shows an example of a suitable facility to conduct radiated immunity testing.

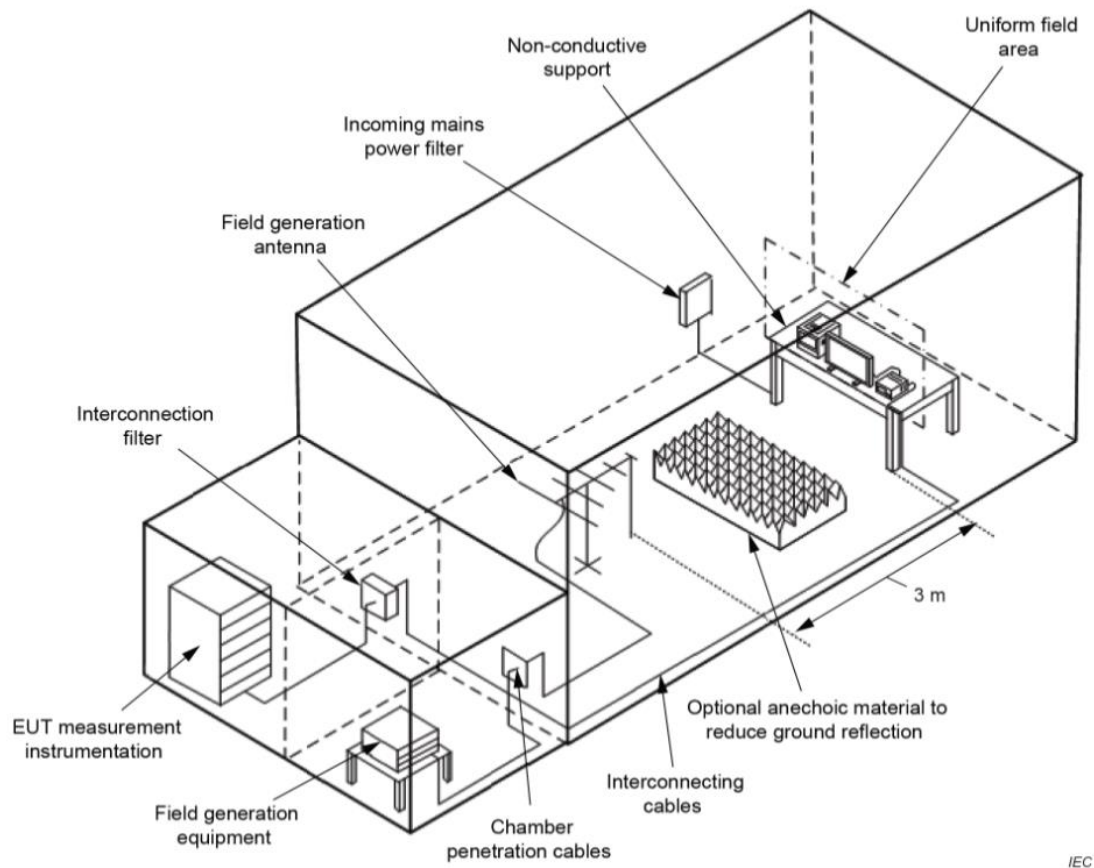


Figure 10. An example of a suitable test facility (EN 61000-4-3 2020, 18).

A power measurement device is needed for assessing forward power during immunity testing. This can include a directional coupler paired with a power meter or alternatively a forward power detector or monitor placed between the amplifier and antenna. These monitor power delivered to the antenna used for consistent field generation across the test setup. It is also recommended to use low-pass or band-pass filters to avoid problems caused by harmonics. (EN 61000-4-3 2020, 17).

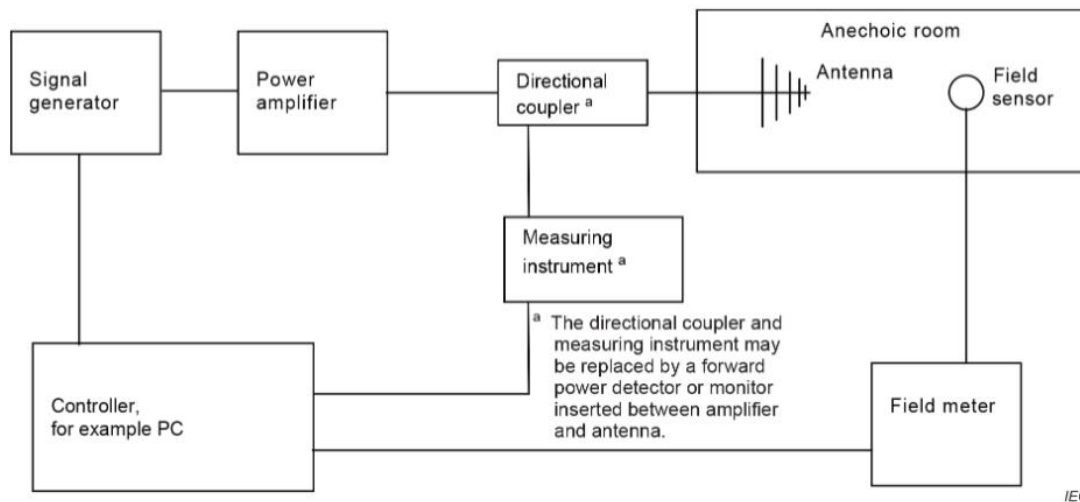


Figure 11. Field uniformity measurement setup diagram (EN 61000-4-3 2020, 23).

Figure 12 shows the measurement setup and how the equipment should be placed inside the room. As is stated in Figure 10 for the measurement the use of absorbers on the floor is not required (EN 61000-4-3 2020, 18), but it is recommended as it is difficult to establish a UFA close to the metallic floor (Landers 2020). The measurement is performed with no EUT in place and without the usual nonconductive table (Landers 2020). Instead Figure 10 suggests to use a special stand made for the use with the isotropic field probe. The probe will be moved along a point grid according to 3.3.1.

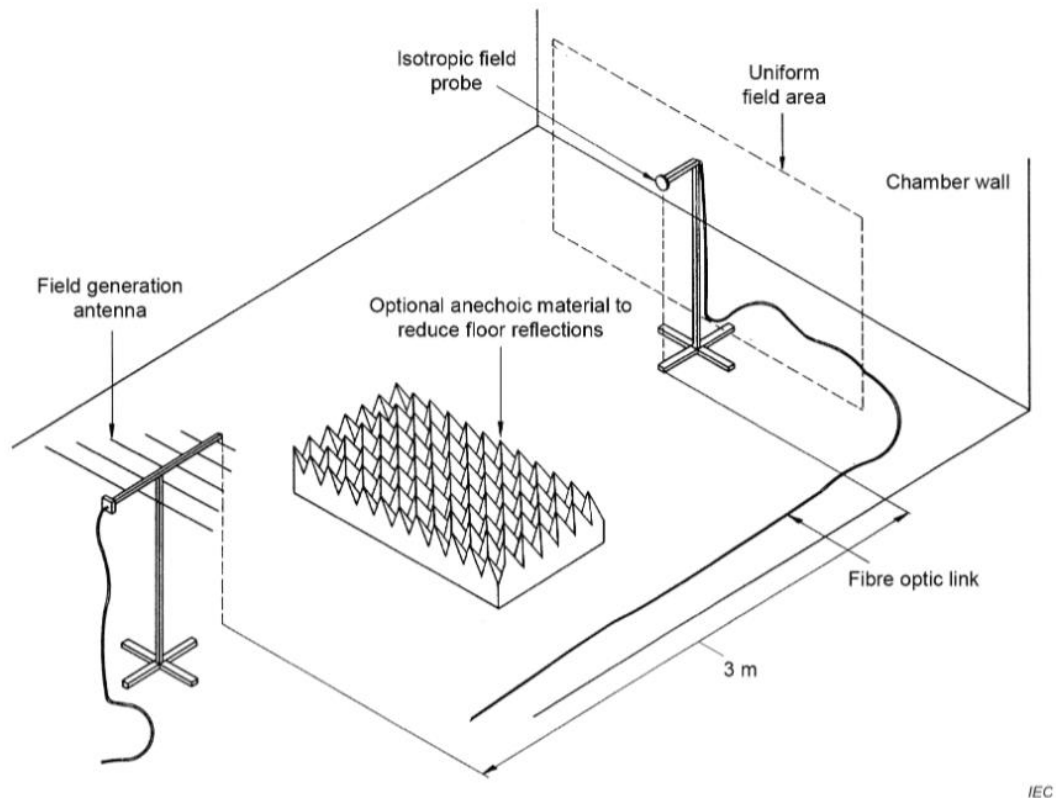


Figure 12. Field uniformity measurement setup (EN 61000-4-3 2020, 19).

3.3.4 Amplifier Linearity

If the linearity of the test system can be demonstrated, the test level can be different from the test level during the calibration (EN 61000-4-3 2020, 19). The linearity must be assessed across the test systems' full amplitude range used for testing. This includes the minimum level, accounting for modulation decreases, and the maximum level, a CW signal level plus 5.1 dB for modulation contributions. For varying field strengths, the evaluation must span all amplifier outputs used. For example, a test conducted at 3 V/m using data from a 10 V/m UFA level setting requires linearity evaluation from outputs corresponding to 1.67 V/m to 18 V/m. (EN 61000-4-3 2020, 43).

The amplifiers linearity must be tested using the same setup as the actual EUT test. Tests are performed at least with minimum, middle and maximum

frequencies or more, if necessary, when for example the amplifiers frequency is split into multiple parts.

The procedure involves determining signal generator settings for the minimum and maximum levels, recording generator output and amplifier power, and incrementally increasing the generator by 1 dB until the maximum value is reached. The gain error shall not exceed 1 dB in the whole output range. (EN 61000-4-3 2020, 44).

3.3.5 Measurement Procedure

To validate field uniformity, a sensor is positioned at each grid point in both horizontal and vertical polarizations. Field strength is measured in the frequency range of 80 MHz to 6 GHz with a logarithmic 2% frequency step size. Forward power is adjusted to match the required field strength, recorded, and applied at all grid points. Results are sorted, deviations are calculated, and a reference field strength is chosen. At least 75% of readings must fall within the 0 to +6 dB tolerance from the reference point. Finally, forward power and system performance are verified to ensure proper operation without saturation as detailed in 3.3.4. (EN 61000-4-3 2020, 24, 25).

4 PRACTICAL IMPLEMENTATION

This section will describe how the site validation tests were done on a real chamber in accordance with the relevant standards for the purpose of accreditation.

4.1 NSA

The measurements were done according to 3.1.4. The antenna positions were selected and placed according to 3.1.3 as shown in Figure 13 and Figure 14. The data was analyzed according to 3.1.5. An absorbing clamp and 10 dB attenuators were used on the cable. They were used for a better impedance match. The impedance mismatch of the signal source and the receiver can cause errors. (EN55016-1-4 2019, 54).

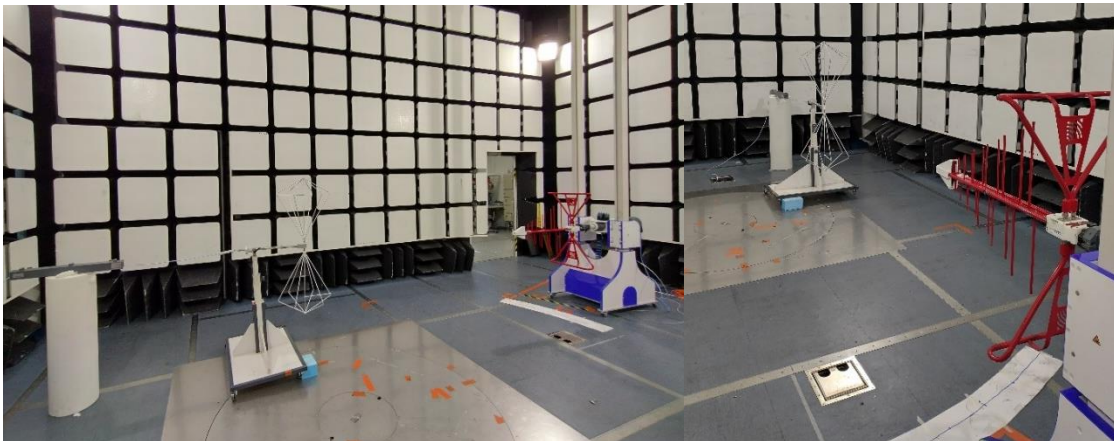


Figure 13. Position right 100cm, polarization vertical, 30 MHz – 200 MHz where the transmit antenna is placed on top of the metal turntable.

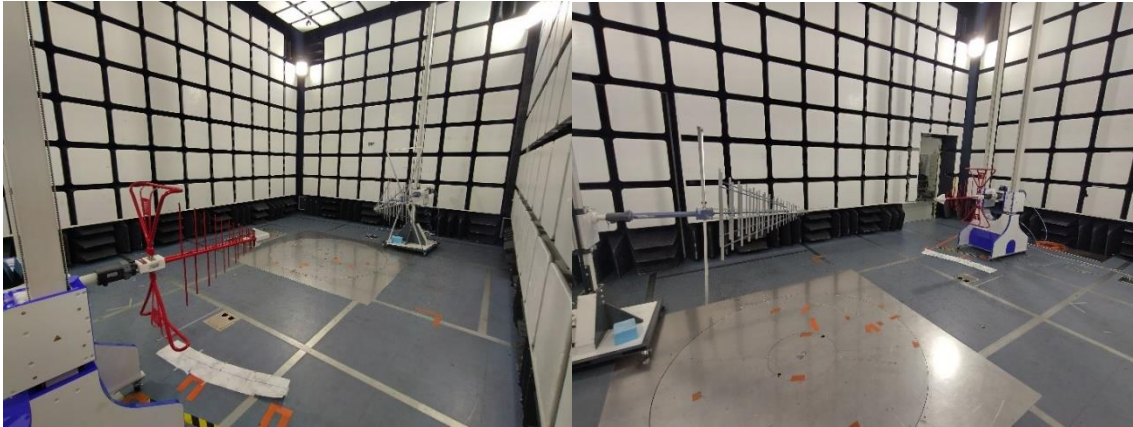


Figure 14. Position right 100cm, polarization vertical, 200 MHz – 1000 MHz where the transmit antenna is placed on top of the metal turntable.

4.2 SVSWR

The measurements were done according to 3.2.4. The antenna positions were selected according to 3.2.3. And the data was analyzed according to 3.2.5. An automatic antenna positioner was used to move the transmit antenna in specific intervals as described in 3.2.3. Calstan 11 was used to measure, analyze and visualize the data.



Figure 15- Position right 100cm, polarization vertical. The red antenna is the receive antenna and the blue is the transmit antenna.

4.3 Field uniformity

The measurements were done according to 3.3.5. The field probe positions were determined according to 3.3.5. And the data was analyzed according to 3.3.5. A

manual antenna positioner was used to move the antenna as shown in Figure 8. The probe was placed on one of the positioners probe holders and moved through the position from the bottom left to the top right. The manual positioners probe holders are 50 cm apart. The uniformity was analyzed using Rohde & Schwartz EMC32 Field Uniformity Analyzer and the amplifier saturation was checked manually according to 3.3.4.

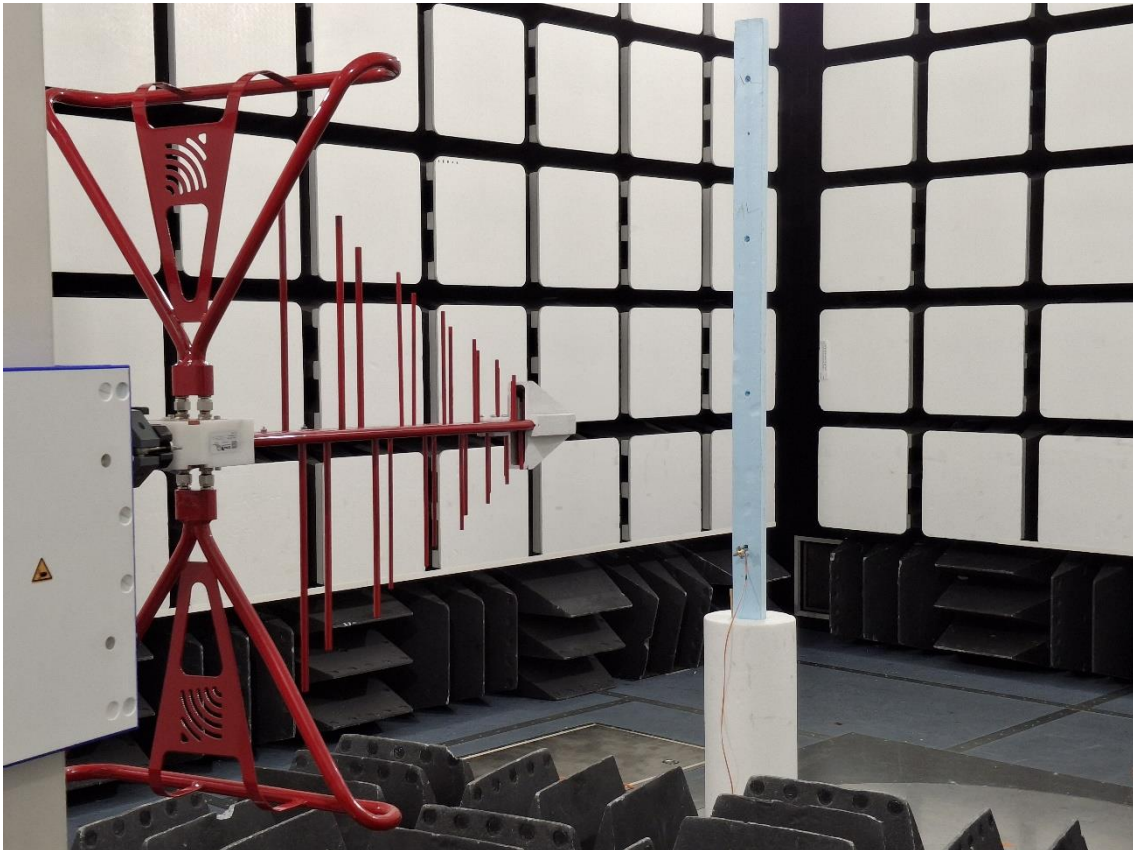


Figure 16. Field Uniformity measurement. The antenna on the left is used as a transmit antenna and the isotropic probe is set on the manual probe positioner.

5 RESULTS

Similar type of measurement results as shown below were used in the accreditation process for showing compliance with the relevant standards. The internal guide for Verkotan to execute the measurements was also created based on 4.

5.1 NSA

In the Figure 17 the deviation of the measured site attenuation from the theoretical value is given. Calculated theoretical NSA values are provided in EN55016-1-4 table 2 for different polarizations and transmit antenna heights. A positive value means that the transmission loss on the site is higher than theoretically calculated. The chamber was found to be in compliance with the EN55016-1-4.

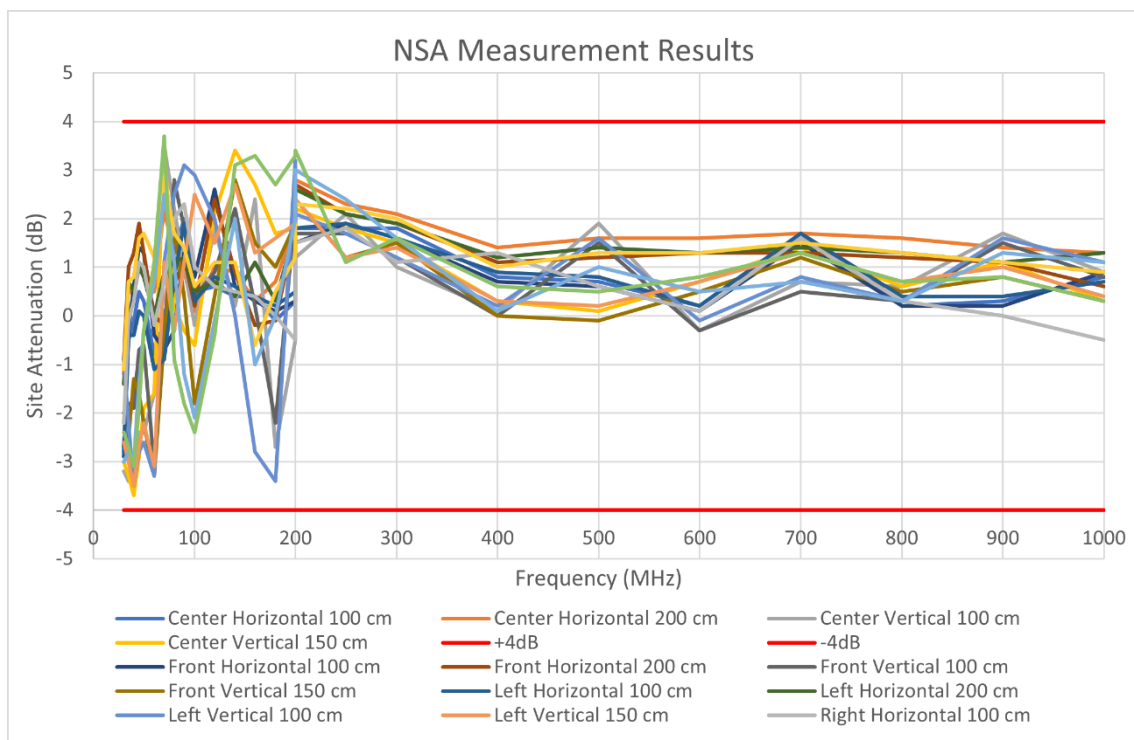


Figure 17. Example NSA measurement data 80 MHz – 1 GHz.

5.2 SVSWR

In Figure 18 and Figure 19 the Site Voltage Standing Wave Ratio is plotted in dB. The chamber was found to be in compliance with the EN55016-1-4. The lines on the graph are named after the positions and the antenna polarization they were measured from. For example, CH is center horizontal, RV is Right vertical, and FH is front horizontal. TH and TV are the extra positions measured at the top of the volume.

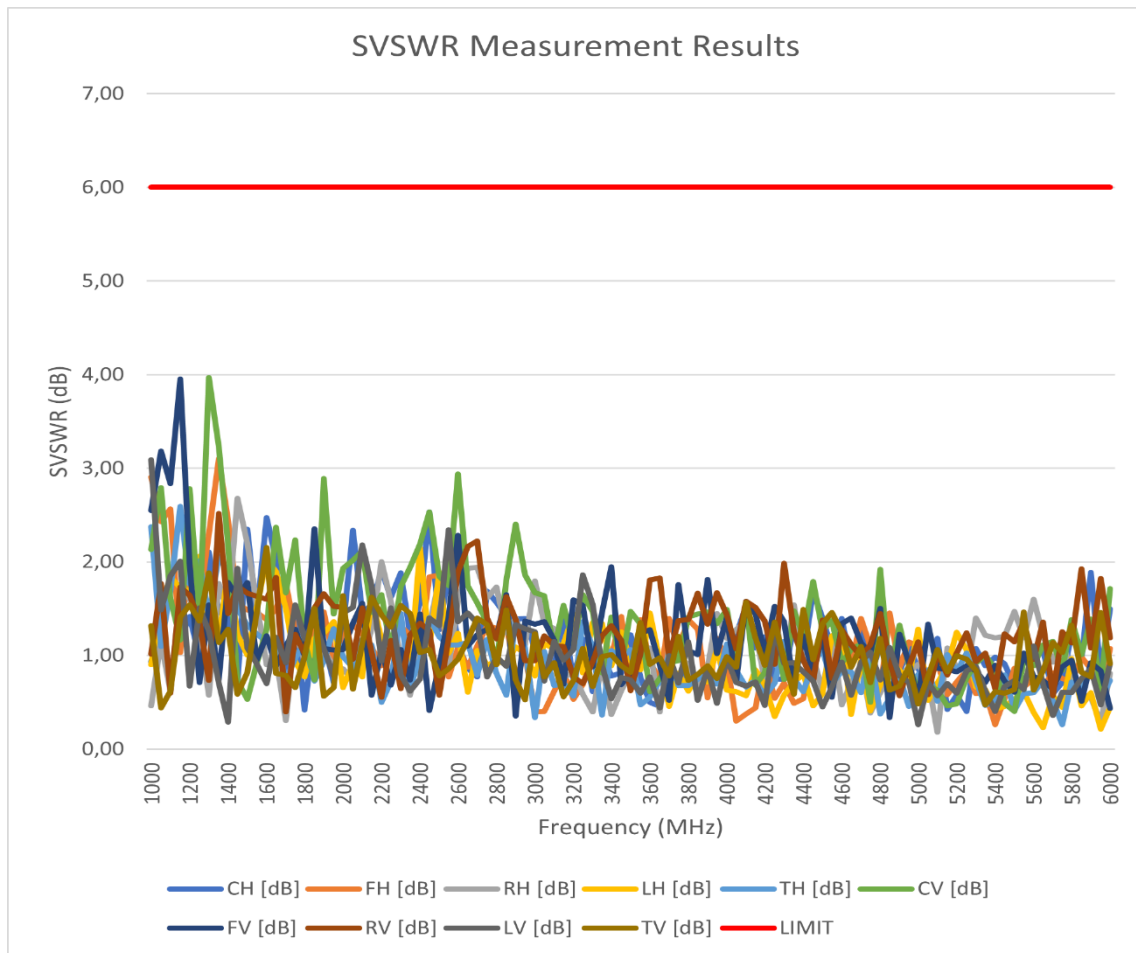


Figure 18. Example SVSWR measurement data 1 GHz – 6 GHz

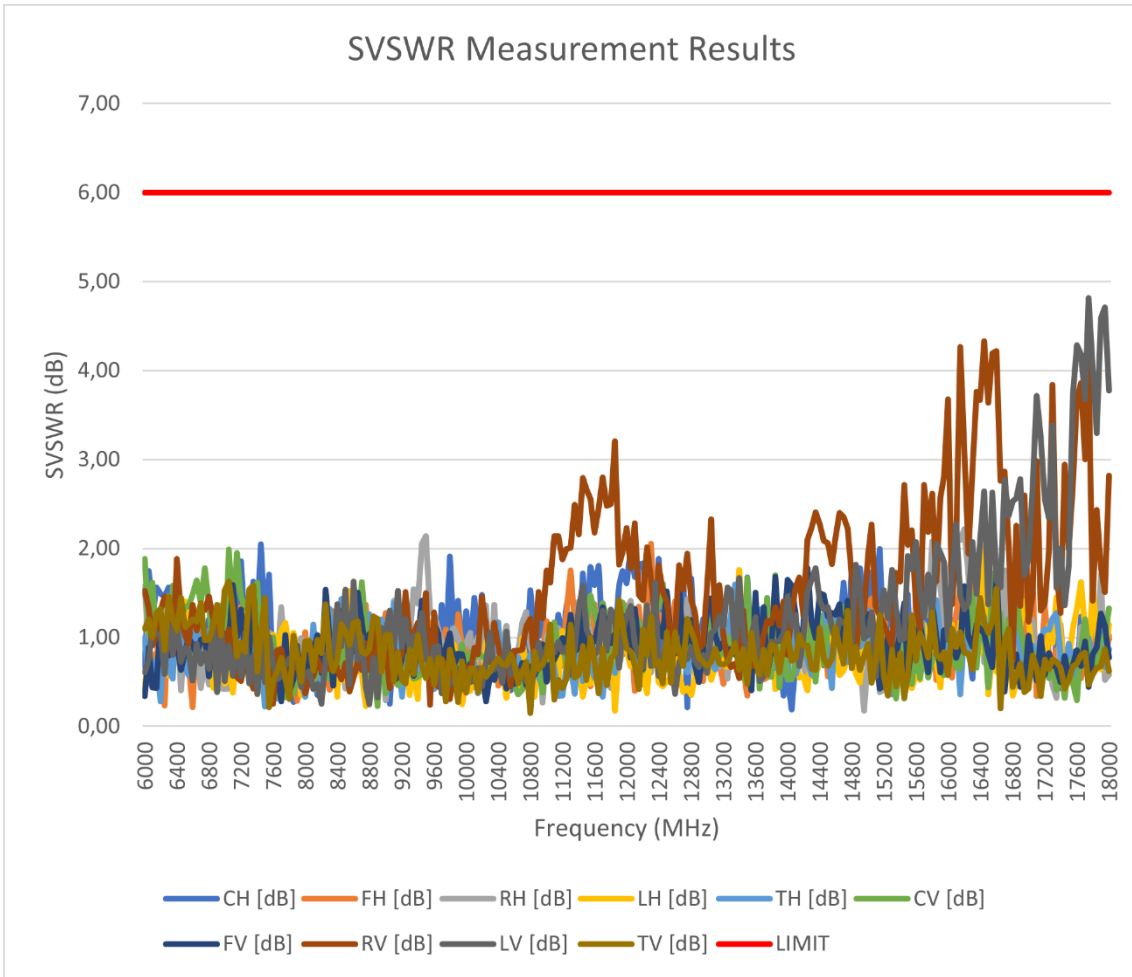


Figure 19. Example SVSWR measurement results 6 GHz - 18 GHz

5.3 Field uniformity

In the Figure 20 and the Figure 21 the field uniformity is visualized using the Rohde & Schwartz EMC32 Field Uniformity Analyzer. The green line is the deviation in dB between the grid points. With the green line only 75% of the points are represented as only 75% of the points must stay inside the 6 dB criterion as stated in 3.3.5. With the blue line the maximum deviation is shown where 0 points can go over the 10 dB limit. The chamber was found to be in compliance with EN61000-4-3.

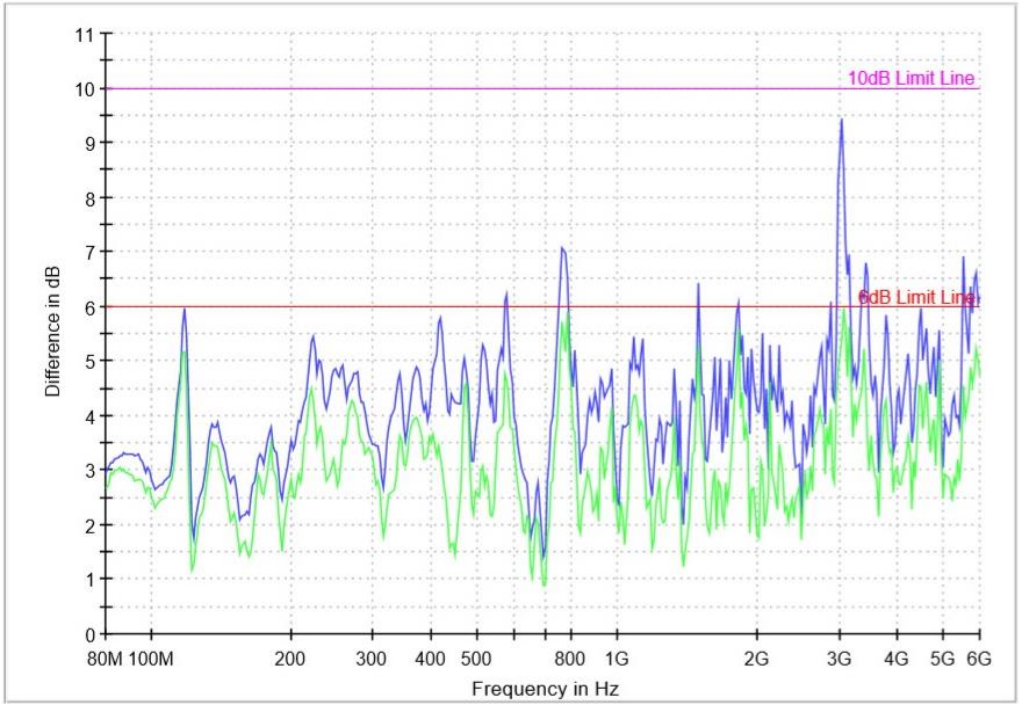


Figure 20. Example data for the field uniformity measurement in horizontal polarization

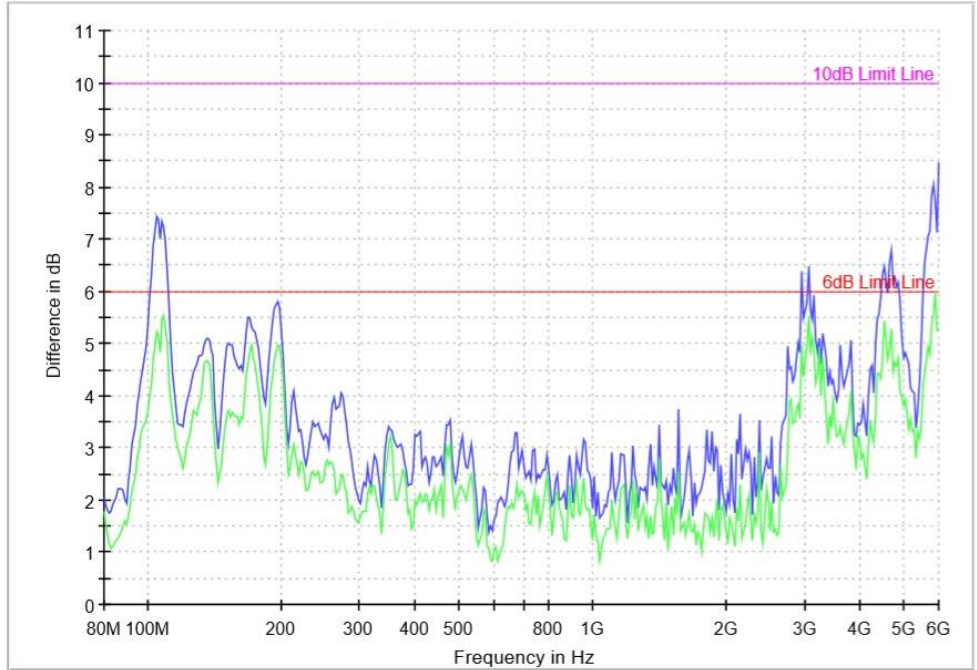


Figure 21. Example data for the field uniformity measurement in vertical polarization

6 CONCLUSION

This paper has presented an in-depth exploration of standardized procedures for measuring Site Voltage Standing Wave Ratio (SVSWR), Normalized Site Attenuation (NSA), and Field Uniformity, as outlined in EN55016-1-4 and EN61000-4-3. These procedures are important in ensuring the accuracy and reliability of electromagnetic compatibility (EMC) test sites.

With the help of this paper and the measurement guides produced for Verkotan, they were able to conduct the measurements and validate the performance of their EMC test site. The data gathered from these measurements was used in showing compliance with international EMC standards. The successful completion of the validation process not only confirmed the test site's readiness for use in compliance testing but also assisted in gaining ISO 17025 accreditation status for Verkotan's EMC facilities.

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