UPPSALA
UNIVERSITET

UPTEC ES 20016
Examensarbete 30 hp
9th June 2020

EMC Test Equipment for 5G at Ericsson

Recomission and optimisation of test equipment for radiated immunity 1-10 GHz

Oliver Djurle

UPPSALA UNIVERSITET

Teknisk- naturvetenskaplig fakultet
UTH-enheten

Besöksadress:
Ångströmlaboratoriet
Lägerhyddsvägen 1
Hus 4, Plan 0

Postadress:
Box 536
751 21 Uppsala

Telefon:
018 – 471 30 03

Telefax:
018 – 471 30 00

Hemsida:
http://www.teknat.uu.se/student

Abstract

EMC Test Equipment for 5G at Ericsson

Oliver Djurle

As demand for 5G networks increase, so does the development of network products. In-house testing is essential during the development stage as it enables faster product releases. A part of in-house testing is the product verification stage that includes electromagnetic compatibility (EMC) tests. These tests ensure that the equipment will not disturb or be disturbed by electric field from itself or other equipment in its vicinity. One of these tests includes function testing of the product in an incident electromagnetic field, called radiated immunity. To perform this test a certain test equipment setup is needed, consisting of a signal generator, amplifier and antenna. It is the antenna that radiates this invisible electromagnetic field that can only be measured with a field probe. Measurements have to be performed in order to define an uniform field area (UFA) in which the incident electromagnetic field is applied to the equipment under test (EUT).

The purpose of the thesis is to develop the radiated immunity operation test procedures and test equipment in order for Ericsson to obtain full in-house EMC testing. Firstly, a theoretical review was conducted on EMC testing standards and procedures. Followed by a theoretical assessment of the current test equipment. Experimental measurements were conducted to validate theory and determine the optimal placement of the test equipment.

The outcome of the thesis is a fully operational in house test setup for radiated immunity 1–10 GHz as well as test instructions that were written on how to perform this test. So that Ericsson can perform all EMC product verification tests during the design stage of their network products.

Key words
5G, internet, network, electromagnetic compatibility, EMC, radiated immunity, test, standard, equipment.

Handledare: Samuel Lundgren Naibei
Ämnesgranskare: Mahbubur Rahman
Examinator: Petra Jönsson
ISSN: 1650-8300, UPTEC ES 20016

Acknowledgements

This thesis would not have been manageable solely on my own, there are people who have been of great importance and help to me. I would like to thank everyone that has helped me in any way, given me a hand and cheered for me. Special thanks has to be directed to:

Åke Strömberg - Manager at thesis department - Ericsson
Samuel Lundgren Naibei - Supervisor of thesis - Ericsson
Mahbubur Rahman - Subject reviewer - Uppsala University
Coworkers at thesis department – Ericsson
Per Isacsson – PI Consulting
Family and Friends

Lastly:
The hobby of Amateur Radio that has made this thesis possible through a wide-spread network of fantastic people all over the world as well as giving me prior knowledge and a passion for antenna and electric field theory.

Executive Summary

This thesis has provided Ericsson with the final piece of operational test setup to acquire full EMC in-house verification capabilities during the design stage of their 5G-baseband products. Allowing Ericsson to quickly and inexpensively perform verification testing during the entire development process and remain a market-leading competitor. This was done by reconfiguration and optimizing of the existing test setup for Radiated Immunity 1-10 GHz that was earlier taken out of commission due to breakdown and uncertain performance. The equipment did previously not meet the specified demands of test-field size that Ericsson had ordered. Now it is clear why the equipment still do not meet that demand, however product tests can now again be performed with a smaller test-field size as before. A solution to this problem is elaborated on, where an investment of a new antenna for the setup can provide this larger test-field size and makes the test more versatile, enabling to test larger products.

Populärvetenskaplig sammanfattning

Testprocedurer och utrustning för framtidens blixtsnabba 5G-nätverk
5G, nästa generations trådlösa kommunikation är på intåg världen över. Det kommer på ett revolutionerande sätt möjliggöra nya användningsområden för trådlös kommunikation, genom att till exempel förbättra upp- och nedladdningshastigheter, bidra till säkrare anslutningar och möjliggöra för helt nya applikationer som till exempel självkörande bilar. För att kunna bygga ett 5G-nät så krävs komponenter som antenner, radioapparater och nätverksbasband. Dessa kräver omfattande produktverifiering under deras utvecklingsfas för att nå marknaden så snabbt som möjligt. Produktverifieringen inkluderar bland annat elektromagnetisk kompatibilitet (EMC), vilket innebär krav på att produkterna inte skall störa eller bli störda internt eller av annan kringliggande utrustning. Testet som behandlats under detta arbete är en del av de elektromagnetiska kompatibilitetstesten och kallas "Radiated Immunity", på svenska påstrålad fältstyrka, som säkerställer att basbanden håller hög standard även i elektromagnetiskt påfrestande installationsmiljöer.

Uppsatsen har utförts tillsammans med företaget Ericsson, som är specialister på nätverksutrustning världen över, och deras avdelning produktverifikation för basband. Vid uppsatsens början hade arbetet med Radiated Immunity-tester sedan tidigare påbörjats, men uppställning av testutrustning och dess resultat var ej tillfredställande och behövde kompletteras.

Testutrustningen för påstrålad fältstyrka består av komplicerade komponenter. Signalen till fälstyrkan som specifierats i internationella standarder för detta test genereras i en signalgenetator som driver förstärkare och skickar vidare en kraftigt förstärkt signal till en antenn som omvandlar denna till elektriskt fält. Detta fält är inte synligt, endast mätbart. För att utföra test i detta fält så krävs det kalibrerade ytor inuti mätkammaren. Dessa osynliga ytor är till stor del beroende av antennens egenskaper som är komplicerade att applicera i praktiken. Därför krävs omfattande mätningar av dessa ytor samtidigt som antennens position justeras.

Efter studier av gällande standarder, ominstallation och optimering av testutrustning teoretiskt och experimentellt kan det konstateras att Ericsson nu har ett användbart system för in-house testning av elektromagnetisk kompatibilitet och Radiated Immunity 1-10 GHz. I uppsatsen redogörs för optimala testuppställningar utifrån teori och experiment, så som bästa placeringen av antenn och test-area, samt dokumentation och instruktioner för användning av utrustningen.

Med möjligheter till komplett EMC in-house testning så slipper Ericsson att hyra in sig på testhus som kan vara köbelagda samt medföra större kostnader. Produkter kan med enkelhet testat på plats under utveklingsfas för att tidigt adressera och åtgärda problem, ett viktigt moment för att snabbt släppa produkter på en marknad med hård konkurrens.

Nyckelord
5G, internet, nätverk, elektromagnetisk kompatibilitet, radiated immunity, test, standard, utrustning

Table of contents

Abbreviations and Definitions

EMC – Electromagnetic compatibility

VSWR/SWR – Voltage standing wave ratio. The ratio between forward and reflected voltage/power on a transmission line

RF – Radio frequent signals/power/transmission

HF – High frequent signals/power/transmission

dBi – Decibels compared to an isotropic radiator, used to compare antennas to a perfect, theoretical isotropic antenna radiating all its power uniformly radially

dB/m – Line attenuation, given in decibel per meter

E-field – Electromagnetic field

UFA – Uniform field area, testing area specified in standards to fulfil uniformity demand in electric field

Field Probe – Measuring device to obtain magnitude of electric field

EUT – Equipment under test

TX – Transmitting, *while under TX*

E-field – Electric field, perpendicular to H-field

EMC32 – Branch standard software for EMC testing, developed by Rohde & Schwarz

Test Equipment – Refers to all equipment in EMC Rack 2 including antennas

Test Equipment Setup - The physical setup/configuration of the Test Equipment

R&S – Rohde & Schwarz

1 Introduction

This chapter gives a brief introduction to the main topics of the thesis, and describes the identified related problems and research gap. Lastly, the purpose, objectives and four research questions are stated.

1.1 Background

Shift from 4G to 5G

When 4G was introduced on the telecom market it came with significantly improved data-speeds, allowing users to extend possibilities of streaming and up/download files. 4G speeds are sufficient to stream HD movies and run the everyday PC tasks. The possibilities with 5G and its superior data speeds compared to 4G, which has already proved sufficient for most users, is vast. More secure connections and faster response times will allow wireless connections to more critical applications, such as self driving vehicles, industry processes, remote working machines etc. These new technologies are essential for the development of a future environmental friendly and sustainable society. The use for 5G reaches a whole new market compared to earlier versions of wireless communications. Therefore, the 5G-market will grow very fast and be well established in the next coming years.

This technology is operating faster and at higher frequencies, and as it advances, the test laboratories and procedures for the test equipment needs to follow the same trend (ETSI, 2019, s. 23). 5G utilize super fast computers which operate with very high clocking frequencies and radio transfer at higher frequencies that allow greater data transfer speeds. 5G is allocated space in some of the high bands between 24,5 – 86 GHz which is considerably higher than what current 4G uses, which is below 6 GHz (Ericsson, Ericsson.com, 2018).

Ericsson and their products

Ericsson is a telecom company founded in 1876, and originally produced telephones. At the rise of the smart phone era, Ericsson discontinued their phone production to focus on their network telecom equipment and belonging services. The company is mostly known for products that connects your phone to the worldwide core grid and allows you to make phone calls all over the world. The portfolio of Network system products includes units such as the tall antennas, radio boxes, flat basebands and complete systems in cabinets, as seen in Figure 1 below.

Figure 1: Ericsson Networks Products - (Ericsson, 2020)

1.2 Problem statement

Electromagnetic compatibility (EMC)

All of Ericsson's products go through full product verification during their development stage. One of the verification stages is Electromagnetic Compatibility (EMC), of which the purpose is to evaluate if the equipment under test (EUT) gets disturbed from other equipment, if it disturbs other equipment or disturbs itself through electromagnetic coupling methods.

These coupling methods arise in the ways that Maxwell, Ampere and Faraday stated a very long time ago. Any current carrying conductor will form an electric field, the same applies in the reverse direction, where incoming electric field will induce a current in a conductor. Combining these phenomena is the principle that is used in for example voltage transformers. However, these phenomena apply to every element that has the ability to carry current whether intended or not. The simplest case of EMC phenomena is two wires lying next to each other. Field generated by current in the first cable will propagate to the second cable and induce a counteracting current. Hence, the second cable will now experience noise from the first cable. Examples as simple as these, as well as more complex ones, arise everywhere in our day-to-day life. Other instances in which this occurs are when phone calls are made in close vicinity to computer speakers resulting in a distinct noise. Another example is how Bluetooth headphones can malfunction when near poorly designed microwave ovens, the fields from the microwave ovens are enough to drown the signal from the phone in the receiver of the headphones. Such scenarios only occur because of improper EMC protection of these products. To summarise, the purpose of EMC testing is to prevent possible equipment failure caused by electromagnetism. Experiencing failures in important communication products from Ericsson could result in dangerous situations e.g. where the availability of emergency services would fall away.

EMC testing

EMC testing includes multiples procedures and is relevant in the scope of this thesis. What is tested is briefly explained below.

Radiated Emission - The E-fields generated by the EUT.
Radiated Immunity - Applying E-field to the EUT.
Conducted Emission - Noise insertion on shielding of cabling of EUT.
RF Common mode - Noise insertion on EUT cabling through induction or direct application.
Burst - Insertion of high voltage on EUT.
Surge - Insertion of high current on EUT.
ESD - Insertion of an electrostatic discharge on the EUT.

Radiated immunity is the test in focus of this thesis.

Testing standards

There are product category standards that specify substandards to all of the tests mentioned above (Telcordia Technologies, 2011) (ETSI, 2016). These are region specific standards that products have to comply with to be sold to consumers in the respective region of the world. Two examples are the European standard ETSI EN 301 489 and the American standard FCC. They refer to substandards that specify what different test-levels and conditions the equipment needs to withstand and under what circumstances it needs to operate. They also specify approved procedures for conducting tests and exposure of the equipment to measuring levels.
For radiated immunity they refer to ETSI EN61000-4-3 that specify levels of electromagnetic radiation, modulation, frequency span, placement, what needs to be tested, etc.

1.3 Research gap

The Baseband Hardware verification department (BB HW) at Ericsson test and verify that all their basebands products will function properly under multiple testing conditions, such as excessive heat, cold, dust, moisture, cycling of usage and EMC among others. The EMC lab is a part of the blackbox lab, which means that it is equipped to do testing on any baseband product, essentially any black box given to test.

In 2017, Ericsson acquired the test equipment that was utilized in this master thesis, in order to test Radiated Immunity 1-10 GHz in their in-house EMC testing chamber. With this new piece of test equipment, Ericsson is fully equipped to conduct all required EMC tests in product verification. This test equipment consists of a complete, plug and play rack solution from Rohde & Schwarz, equipped with signal generator, amplifiers, network remote control with switching, compressor unit and two antennas on rotatable mounts. The rack was designed, delivered and installed by Rohde & Schwarz. Their previous experience with installations of EMC-chambers tell that it is very difficult to correctly dimension the test equipment solely on theory since the chambers all show different characteristics and results (Isacsson, 2020). Hence, the design of EMC Rack 2 was based on prior experience and knowledge from earlier chamber installations. What differentiates Ericssons chamber from this prior knowledge is its size. It is considerably smaller. This made the choice of amplifier power levels and antennas more difficult.

Gap 1: Installation and performance of EMC Rack 2
The installation of this new rack was done under quite a short period of time, hence the installation process was rushed and the test equipment did not meet its full demands. An uniform field area (UFA) of 1,5 x 1,5 m is the most commonly chosen size since it is the minimum size required for using the partial illumination method (ETSI, 2019). The size of the UFA was discussed between Ericsson and Rohde & Schwarz sometime during the ordering/delivery process and it was concluded that an 1,5 x 1,5 m UFA would not fit in Ericsson's EMC-chamber and that the goal was to achieve an 1,0 x 1,0 m UFA.

Figure 2 below shows the performance of the test equipment when an 1,5 x 1,5 m UFA was tested with a 16- point calibration. The entire graph will be explained more thoroughly in the theory section. However, to put it simply all points “P1, P2, P3, ...” are supposed to lie over the straight line representing “test level”. As seen, all points except those which represents a 0,5 x 0,5 m UFA (P6, P7, P10 and P11) fail the test levels between 2,2 - 6 GHz. Hence, a 1,5 x 1,5 m UFA was not possible in the installation process.

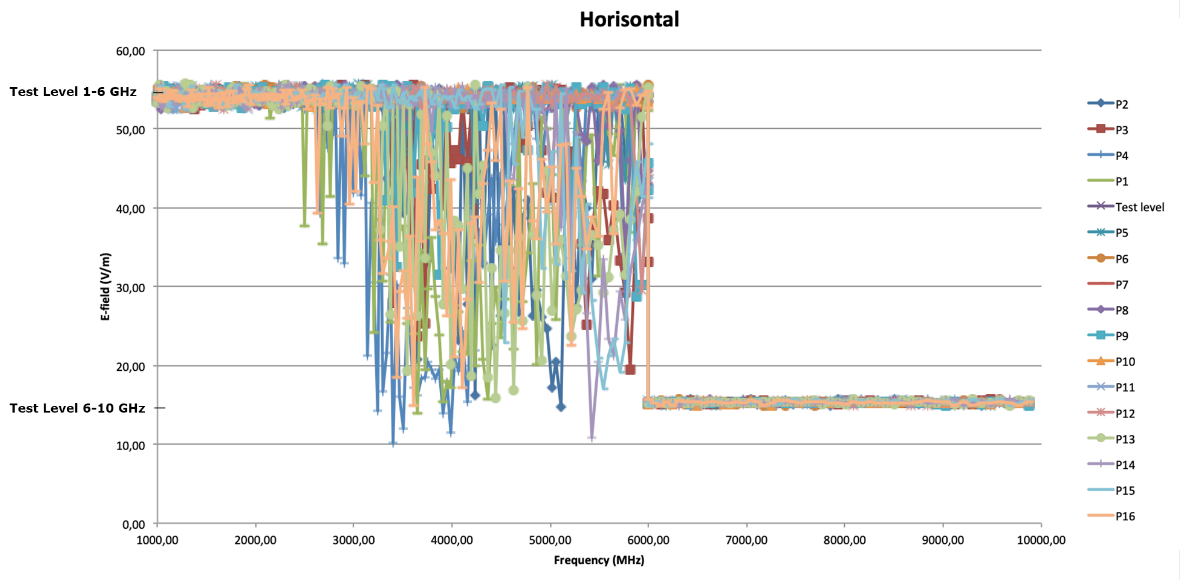


Figure 2: Electric field measured during test calibration of 1,5 x 1,5 m UFA pre-thesis

As seen by studying the graph over power in Figure 3 below it is shown that the peaks reach the max output levels between 2 - 4,5 GHz.

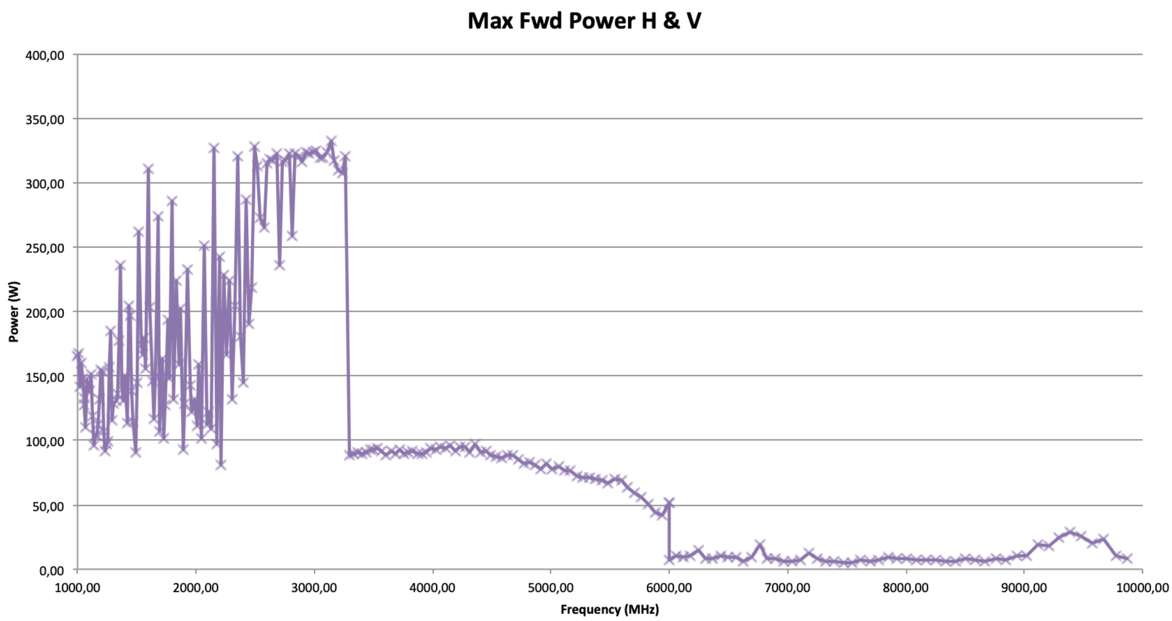


Figure 3: Output power level measured during test calibration of 1,5 x 1,5 m UFA pre-thesis

The points in Figure 4 below represent a 0,5 x 0,5 m UFA that fulfil the test levels.

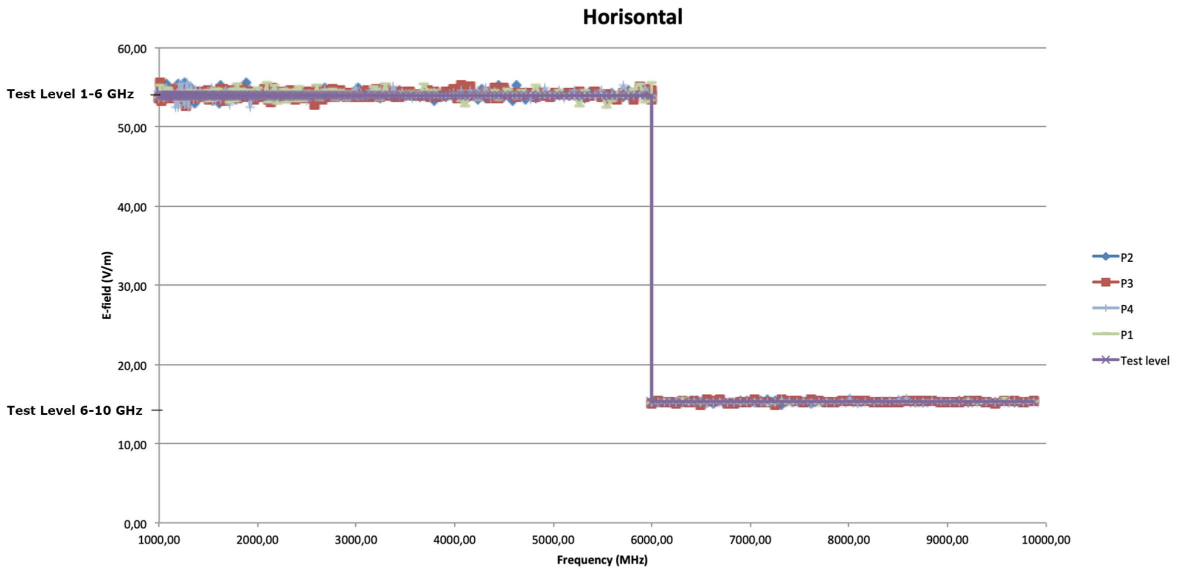


Figure 4: Electric field measured during test calibration of 0,5 x 0,5 m UFA pre-thesis

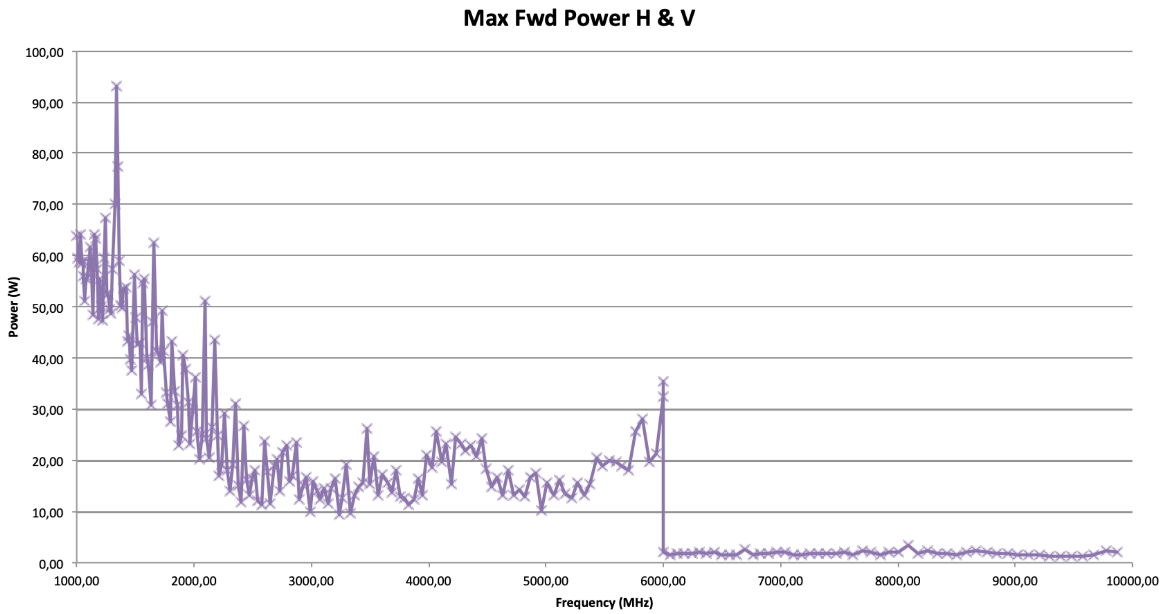


Figure 5: Output power level measured during test calibration of 0,5 x 0,5 m UFA pre-thesis

As seen in the power level for the 0,5 x 0,5 m UFA, Figure 5 above, the test equipment output levels are significantly lower than of the attempt with a 1,5 x 1,5 m UFA in Figure 3 above.

To summarise, there was not enough time for the engineer from Rohde & Schwarz to optimize the installation of the test equipment to reach its full capabilities. Ericsson was left with an 0,5 x 0,5 m UFA.

Gap 2: Practical operation issues
When the rack was later supposed to get taken to use it was considered unpractical and a workplace hazard because of its size and weight. The heavy rack (100-200kg) needed to be pushed up a ramp into the EMC chamber. Due to the large size of the frame, the antennas had to be dismounted from the rack if it was to be moved. The larger antenna weighs approx. 8 kg and had to be fitted at shoulder height on a pipe with a very low clearance. It was decided to permanently install the rack outside of the chamber.

Moreover, shortly after the rack was to be taken into use, an amplifier TX broke and the rack was taken out of commission. The amplifier was sent to be repaired by the manufacturer Bonn Elektronik, which is a partner company to Rohde & Schwarz. By the starting point of this thesis in February 2020 there was still no amplifier available for the 6-10 GHz range. However, in April, Rohde & Schwarz lent an amplifier to Ericsson in order for the thesis to have all equipment in place.

1.4 Purpose

The purpose of thesis is to develop the radiated immunity operation procedures and test equipment for 1 – 10 GHz in order for Ericsson to obtain full in house EMC testing.

1.5 Objectives

To reinstall and calibrate EMC Rack 2 by:

- Research standards to find demands to fulfil
- Analyse the test equipment available and its theoretical performance
- Install the rack in its new position
- Experimentally verifying theory and find optimal placement of antenna
- Creating a calibration for product testing and writing operating instructions

1.6 Research questions

RQ1 - What practical measures has to be taken to install EMC Rack 2 in its new position?
RQ2 - Where is the most optimal position of the antenna in the chamber?
RQ3 - Does the reference calibration fulfil the demands from standards and correspond to the theoretical performance of EMC Rack 2?
RQ4 - What will be the operation procedure of this setup?

1.7 Delimitations

The following is set as delimitations for this thesis:

- Only available test equipment in the rack, as well as antennas is examined.
- No new antennas will be ordered due to waiting times. However, future outlooks will discuss what can be bought to optimise further.
- No reconnections of signal paths within EMC Rack 2 will be done except to install the loan amplifier.
- Measurement uncertainty will not be elaborated on since it has formerly been satisfactory.

2 Theory

This section delves into the already existing theoretical foundations on which the thesis is based. It also includes calculations that serve as a starting point for the experimental process.

2.1 Standards and measuring procedures

Standards

The testing on Ericsson's products needs to follow worldwide standards to meet market demands as well as internally demanded test levels. The standards that are tested during the verification stage in Ericsson's Kista office are the European ETSI EN 301 489 and American FCC standard. Their hierarchy is presented in Figure 6 below. These will specify at which E-field levels we test as well as how we perform a test.

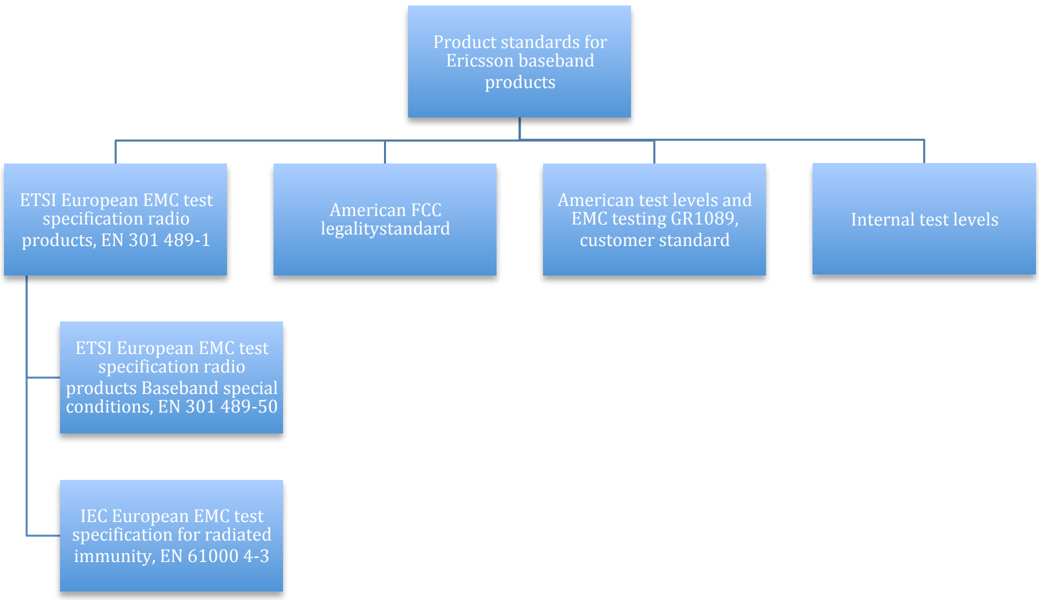


Figure 6: Standards for radiated immunity testing

European Product Standard – ETSI, EN 301 489-1

The generalized radio product standard is EN 301 489-1, it states that for baseband products, special care should be taken in to account according to 301 489-50. It also refers all radiated immunity testing to 61000 4-3, which 301 489-50 also does, where all procedures and levels are specified.

Test level:
For the frequency range 80 MHz - 690 MHz, test level shall be 3 V/m
For the frequency range 690 MHz - 6 000 MHz test level shall be 10 V/m

These shall be applied with a 1 kHz sinusoid that is amplitude modulated to a depth of 80%. Below shows an example of a 1 V/m field that is modulated accordingly. The first 2 ms are unmodulated, after 2 ms the modulation is added. To find an UFA that will not include distorted modulation, the testing points needs to achieve a E-field level of 1,8 x the test level.

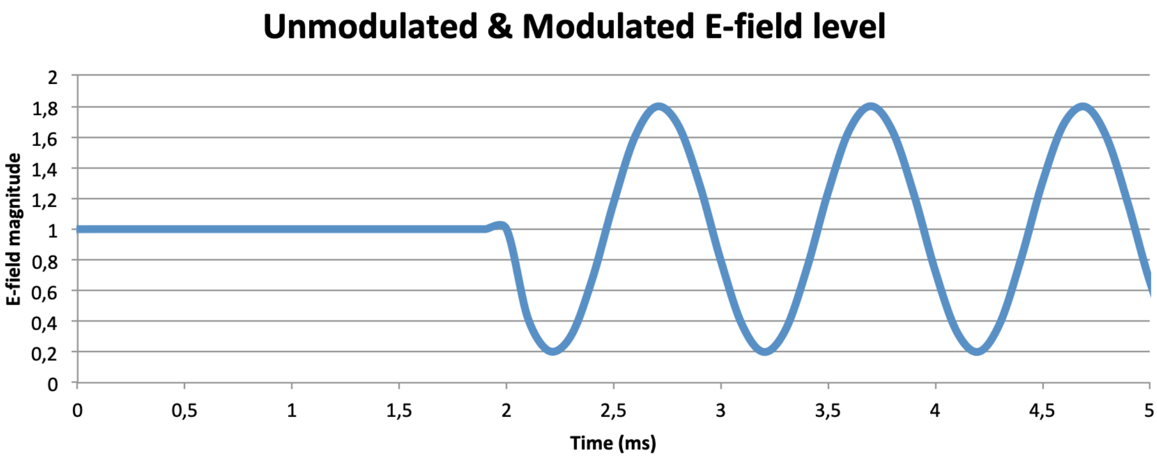


Figure 7: Example of modulation requirements according to IEC 61000-4-3

The testing procedure should be applied as the standard IEC61000-4-3 specifies, this is explained below in Testing.

(ETSI, 2016) (ETSI, 2019) (IEC, 2006)

American Standards Levels
The customer standard GR1089 states the following test levels:

Test level: For the frequency range 10 kHz – 10 GHz, test level shall be 8,5 V/m
The test level shall be modulated as in IEC61000-4-3 with a 1 kHz 80% modulation.

(Telcordia Technologies, 2011)

Testing Levels
Highest legality levels combining American and European standards are as follows:
For the frequency range 10 kHz to 80 MHz, test level shall be 8,5 V/m
For the frequency range 80 MHz to 690 MHz, test level shall be 8,5 V/m
For the frequency range 690 MHz to 6 000 MHz test level shall be 10 V/m
For the frequency range 6000 MHz to 10 000 MHz test level shall be 8,5 V/m

Many sources debate whether these limits are corresponding to real life situations and it is often concluded that they will under-test the EUT (Armstrong, 2007).

Ericsson Test Levels
Out in the field the products are often installed in technical rooms where customers might place much other equipment generating disturbing fields. If the legality levels are lower than the fields in this environment, the products might malfunction even though it fulfilled standard demands. A scenario like this would end up in a large setback for Ericsson, the product would have already reached the market. Altering current production would cost a substantial amount of money and time. To prevent these scenarios, Ericsson has internal test levels set on over-testing the product.

Current internal test levels for testing indoor products are:
For the frequency range 80 MHz to 400 MHz, test level shall be 10 V/m
For the frequency range 400 MHz to 6 GHz, test level shall be 20 V/m

Current internal test levels for testing outdoor products:
For the frequency range 80 MHz to 400 MHz, test level shall be 10 V/m
For the frequency range 400 MHz to 6 GHz, test level shall be 30 V/m

Summarising all the legal, customer and internal levels for the interval of 1-6 GHz that is the scope of this thesis, the points of the UFA need to fulfil:
For the frequency range 1 GHz to 6 GHz, test level with modulation is 54 V/m
For the frequency range 6 GHz to 10 GHz test level with modulation is 15 V/m
To fulfil the modulation levels shown in Figure 7 above.

Measuring
The standard EN 61000-4-3 states how a test should be performed (IEC, 2006). The NEBS standard GR 1089 refers the testing procedure to be carried out as EN 61000-4-3 (Telcordia Technologies, 2011). EN 61000-4-3 is very detailed and all information will not be taken into consideration. What is essential for this thesis however are the following points:

- The test shall be carried out in an anechoic/semi anechoic chamber and all results shall be reproducible.

- The given test level shall be modulated with a 1 kHz sine wave, modulation depth 80%.

- Every face of the EUT shall be tested with both horizontal and vertical antenna polarisation. All necessary cabling shall be illuminated by the UFA.

- The uniform field area (UFA) shall start at 0,8 m above grounded floor level and be at least 0,5 x 0,5 m large, preferably 1,5 x 1,5 m large. Measuring points are spaced in a mesh with 0,5 m distance between. They are denoted 1, 2, 3, … in the same pattern a western book is read.

- The calibration of UFA states that all points has to fulfil electric field-strength level that is 1,8x the test level to accommodate for the 1 kHz modulation. 75% of the points must lie between (0,+6dB) of the test level. This span is considered the best conditions/smallest deviation achievable at an arbitrary anechoic chamber. For a small UFA of 0,5 x 0,5 m, all points must lie within this interval.

2.2 Test equipment setup

*The hardware that previously arrived as one complete moveable unit with antennas mounted on the rack can be subdivided, and all three major parts of the entire setup will be considered as **the rack, the antennas and the chamber**.*

EMC Rack 2

The test equipment in EMC Rack 2 is specified in Figure 8. The relevant test equipment for this thesis specifically are four amplifiers and a signal generator. Two of the amplifiers are the same model and are phased to add the output power.

Amplifiers

The amplifiers in EMC Rack 2 and their power levels listed according to the frequency range they operate in:

- R&S, 0,69 – 3,2 GHz, in this range two 200 W amplifiers are set to operate in phase, providing the added output power of 400 W.
- R&S, 2,5 – 6 GHz, one amplifier with forward power 100 W.
- Bonn, 6 – 10 GHz, one amplifier with forward power 50 W.

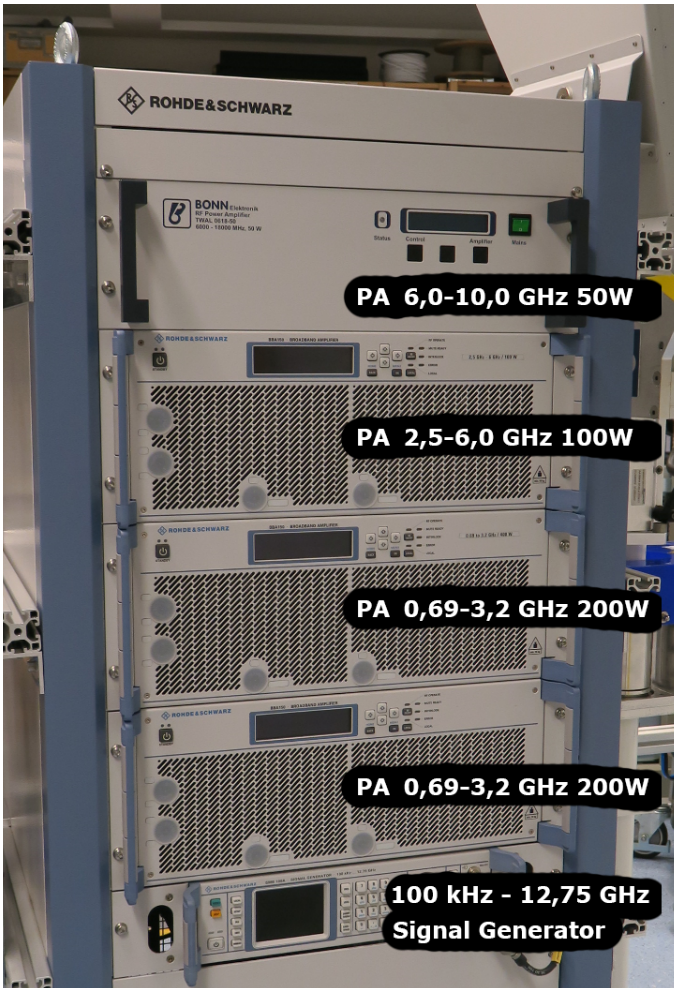


Figure 8: Test equipment in EMC Rack 2

VSWR and Amplifier Protection

The Rohde & Schwarz amplifiers has SWR protection "foldback" built in, meaning that if the measured VSWR rises above 6:1 the amplifier will reduce output power so that the reflected power will not reach harmful levels. In practice this means that the Rohde & Schwarz amplifiers are protected from damage in situations when high VSWR arises for example if coupled with badly matched or faulty antenna systems or in cases with bad connection at a cable terminal. (Rohde & Schwarz, 2019, p.58 & 70)

The Bonn amplifier does not state any amplifier protection/power foldback in the operation manual version 8-E that was supplied with the Bonn amplifier in 2017. Though the latest amplifier specification on Bonn's website, which is undated and updated without notice, states that the amplifier has infinite mismatch protection. Through previous internal Ericsson experiences with Bonn amplifiers it has been established that they are fragile to high VSWR and can destroy themselves if the system is not properly matched. Hence, low power level should be used to sweep the frequency range in order to make sure that the system has no intervals with high VSWR before high power and possible high reflected power is to be used. From this information, only Bonn knows if our amplifier has built in VSWR protection or not.

Signal Generator

The signal generator in the rack has a frequency span of 100 kHz – 12,75 GHz and is sufficient to drive all amplifiers in the rack.

Cabling

The previous cabling used has been UFB239C that has good properties and quality. For the new experimental setup of EMC Rack 2 more cables are needed and at different lengths than before, which can be found in the black box lab storage at Ericsson. The specific requirements for cables to be used are as follows:

Characteristic Impedance

The characteristic impedance of all test equipment used in this thesis is the standard 50 Ohms. When looking for temporary cabling in the lab storages, all cabling with other characteristic impedance e.g. 75 Ohms is sorted away.

Connector type

There are many connectors used between all EMC test equipment, everything from small SMA connectors to larger 7/16" connectors. Since antennas will be interchangable from the RF outputs and chamber wall connector, the standard N connector is used throughout this signal path outside of the EMC Rack 2.

Breakdown Voltage

When finding cabling to use with the setup the insulation breakdown voltage should be taken into consideration. This is to make sure that the cable should not break during the worst-case scenario high voltage/VSWR on the line. Following calculations define the highest voltage obtained from infinite VSWR:

The voltage reflection coefficient is defined as: (Balanis, 2016, p.61)

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \qquad (-) \qquad (1)$$

Where Z_{in} = the impedance of the new medium
Z_0 = the impedance of the transmission line
For $\Gamma = 0$ we have a matched system where no voltage is reflected on the line.
For $\Gamma \rightarrow 1$ we have an unmatched system where voltage is reflected on the line.

In the worst case scenario the new impedance equals infinity (open connection), which equals a reflection coefficient of 1.

The VSWR is defined as: (Balanis, 2016, p.61)

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \qquad (-) \qquad (2)$$

A reflection coefficient of 1 will give us infinite VSWR. Meaning that all forward voltage will be reflected back on the line at the terminal of our mismatched impedances. The peak voltage that will appear on the line must therefore be equal to the sum of the forward power and the reflected power at both of their maximas when causing constructive interference with each other. At the worst-case scenario $\Gamma = 1$ which means that the reflection will be equal to the forward voltage. Thus giving us:

$$V_{peak} = 2 * \sqrt{2} * V_{fwd} \qquad (V) \qquad (3)$$

The forward voltage can be calculated from the power rating of the amplifier and impedance of the system itself using the power equation (4).

$$P_{fwd} = \frac{{V_{fwd}}^2}{Z_0} \Leftrightarrow V_{fwd} = \sqrt{P_{fwd} * Z_0} \qquad (W) \qquad (4)$$

Combining equation (3) and (4) gives us the following (5):

$$V_{peak} = 2 * \sqrt{2 * P_{fwd} * Z_0} \qquad (V) \qquad (5)$$

Inserting numbers into the equations results in:

$$V_{peak} = 2 * \sqrt{2 * 400 * 50} = 400\,V \qquad (6)$$

Note that this calculation does not include any line attenuation. This is to make it valid for any possible bad connectors near the amplifiers or the antenna. This result is a higher value, which is considered extra safety measure of the new cabling. Performing these safety calculations was recommended by Per Isacsson (Isacsson, 2020).

Antennas

The two antennas that were chosen when the test equipment was initially designed are broadband horn antennas that are designed for this sole purpose of EMC testing. Several parameters of the antennas are of interest to understand their behaviour and to model the test equipment's capabilities. Unlike amplifiers who only have a certain power level, an antenna has multiple parameters that depend on its physical dimensions and also change with frequency. The most important properties to examine are: gain, beamwidth, near and far fields and lastly VSWR.

<u>Gain</u>

The gain of the antenna is essential for evaluating its radiative properties in one direction. It is a logarithmic measure of how effective the antenna is in one direction compared to an isotropic radiator, dBi. The isotropic radiator is only theoretical and does not exist in reality since it is modelled as a point source of radiation. This point source radiates E-field with equal radial distribution for all angles. All antennas that are not a point source will radiate more in some direction/s and less in others compared to the isotropic antenna. The ratio of these is what is presented as dBi.

The gain is highly frequency dependent for most antennas and is therefore presented in the antenna specification for all values of the antennas total bandwidth.

<u>Beamwidth</u>

The uniform field area requested by Ericsson was 1,0 x 1,0 m, which is represented with 9 test points spaced over the area in a matrix pattern with distance from point to point of 50 cm according to EN 61000-4-3. As also stated in 61000-4-3 is the demand of uniformity between the points in the area is that at least 75 % of the points must lie between -0 dB to +6 dB of the chosen test level of V/m, in other words the beam width in this case is twice the angle from maximum gain of the antenna to – 6dB.

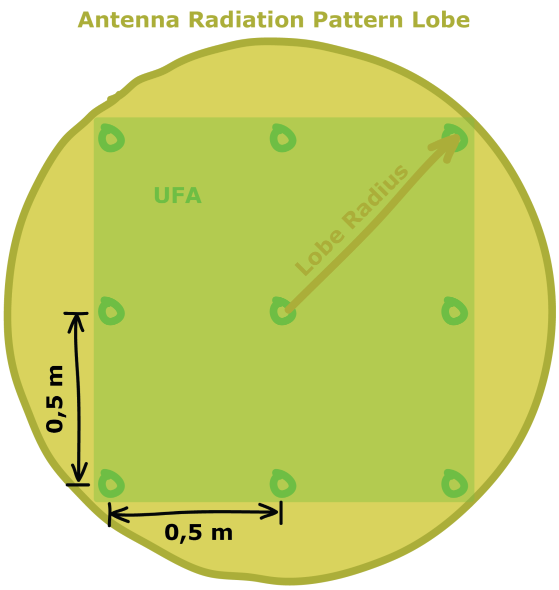


Figure 9: Circular antenna radiation pattern covering all points of square UFA

The distances in Figure 11 between the antenna and the UFA is denoted "D" and can be calculated geometrically through the following equation:

$$D = \frac{\frac{\sqrt{2} * X}{2}}{\tan\theta} \qquad (m) \tag{7}$$

"X" denotes the length of the UFA's square sides X * X m.
"θ" represent half of the -6 dB beamwidth angle of the antenna.

The Antenna specifications state that both of the antennas get narrower gain lobes as the frequency increase. (Schwarzbeck Mess - Elektronik, n.d.) (Schwarzbeck Mess - Elektronik, n.d.). During a full frequency sweep test it is not possible to accommodate for this by bringing the antenna forward and backward with respect to frequency tested because of practical reasons, hence we must choose to place the antennas at a static position for the narrowest lobe/difficult case.

The lobe in the specifications is shown in Figure 10. It is denoted with H-plane as a standard for a horizontally polarized antenna. The magnetic field H is always perpendicular to the electric field E which denotes the vertical plane. (Schwarzbeck Mess - Elektronik, n.d.)

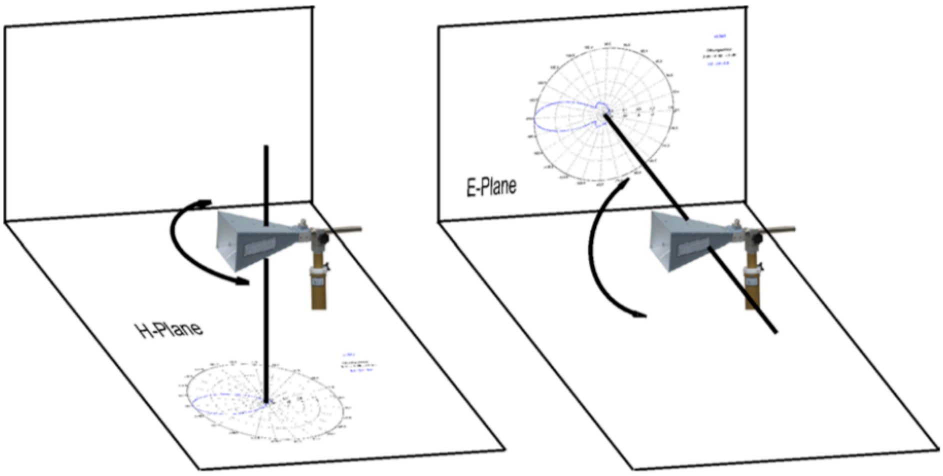


Figure 10: Definition of antenna H & E-planes - (Schwarzbeck Mess - Elektronik, n.d.)

The specifications for both antennas state values of angles at half power beam width (HPBW). This is twice the angle from centre (max gain) to where the signal level is 3 dB lower in magnitude.

Since the UFA uniformity condition on E-field is (0,+6 dB), the angles of interest is read where the blue curves cut the -6 dB scale. The same concept as for HPBW angles but for "Quarter Power Beamwidth", -6 dB instead of -3 dB. This angle can be used to calculate antenna placement in the chamber as in Figure 11, that would in theory place the corner points at 0 dB and the middle point at +6dB relative them. Just as the boundary condition of the standard. For this case the antenna is as close to the UFA as possible. If the antenna and UFA are placed further apart as in Figure 11, the angles to cover the UFA in the beamwidth will decrease and get closer to the HPBW 3 dB angles. This would give us a difference of

3dB between the corner points and the centre point and thus a more homogenous field. Figure 11 below illustrates this.

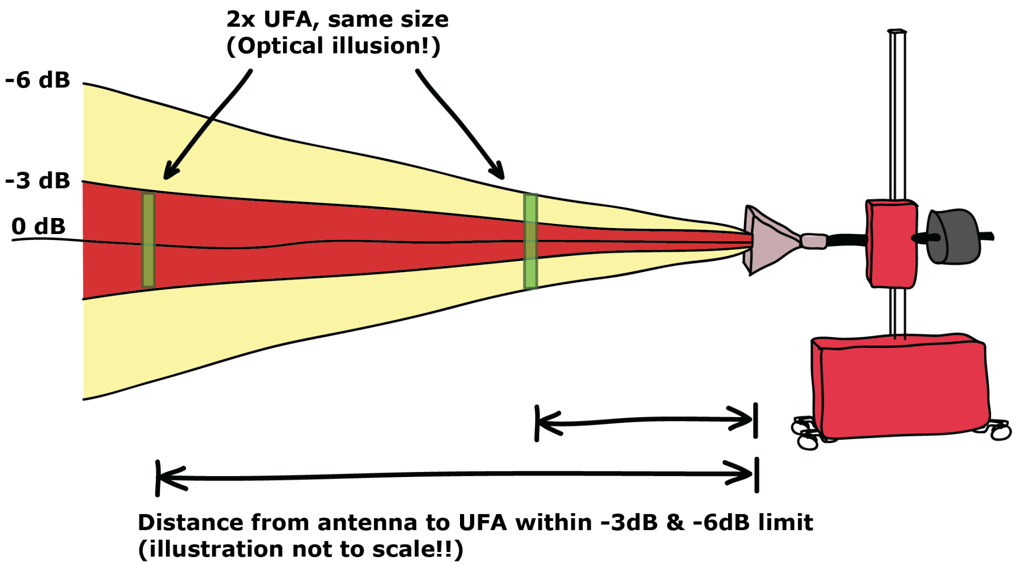


Figure 11: Antenna beamwidth to cover UFA with respect to distance

Near and Far Field

Since the entire antenna is in resonance with the transmitted RF, every part of it will radiate. The radiation from two arbitrary points of the antenna will radiate outward, causing constructive and destructive interference. Much like the waves on the waters surface when creating waves with two sources next to each other. Every point on the antenna will contribute to these interferences and at a certain distance from the antenna, the nodes of constructive and destructive interferences will have somewhat aligned to a homogenous wave front. This region of homogenous wave fronts is called the far field region or Fraunhofer region. It is in this region the behaviour of the electromagnetic waves is predictable and the derived equations will give valid results. There is no general established formula for where the near field region ends and far field region begins that is valid for all antennas. The result for every antenna is different and it depends on the wavelength and the physical dimensions of the antenna. Since EMC testing sweeps frequency, the far field boundary calculated with equation (9) will vary. The furthest distance that appears in this thesis will be most interesting since it describes the case where theory is stated to be less accurate. (ARRL - Amateur Radio Relay League, 2007, p.43)

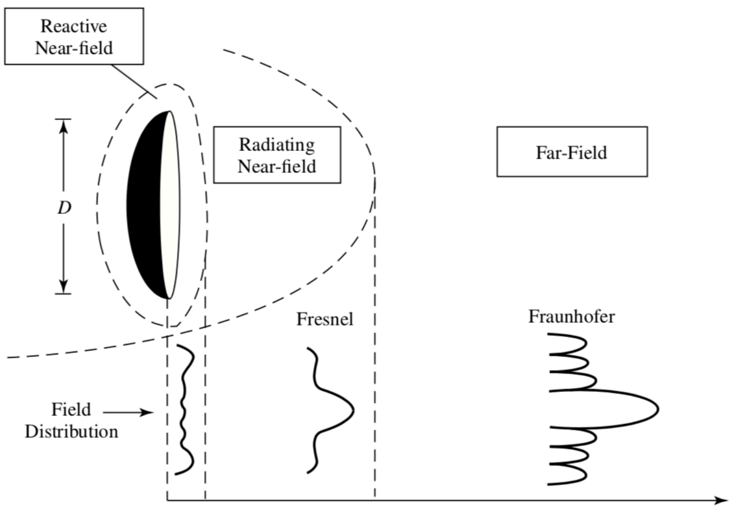


Figure 12: Radiating field regions, example from dish antenna - (Y. Rahmat-Samii, 1995)

The equation for the radiating near field region is: (ARRL - Amateur Radio Relay League, 2007, p.43)

$$D_{Fresnel} = 0{,}62 * \sqrt{\frac{L^3}{\lambda}} \quad (m) \tag{8}$$

The equation for the far field region, also called Fraunhofer region is: (ARRL - Amateur Radio Relay League, 2007, p.43)

$$D_{Fraunhofer} = \frac{2 * L^2}{\lambda} \quad (m) \tag{9}$$

Where “L” is the largest physical dimension of the antenna face, in the same units as lambda. The equation (9) is derived with respect to the phase differences from two radiated signals initiated from the middle of the antenna and the furthest point from the middle (D/2) that shall not differ more than 1/16 wavelength (US Naval Air Warfare Center, 2013).

VSWR

The voltage standing wave ratio for any antenna will vary with the wavelength. Any antenna has an optimal resonant frequency where its impedance will be closest to 50 Ohm impedance. However, changing the design of the antenna can allow it to be fairly resonant over a larger area of frequencies resulting in a broader banded antenna. For a number of reasons it is of interest to keep a low VSWR. This is explained further in ”modelling of test equipment setup” below.

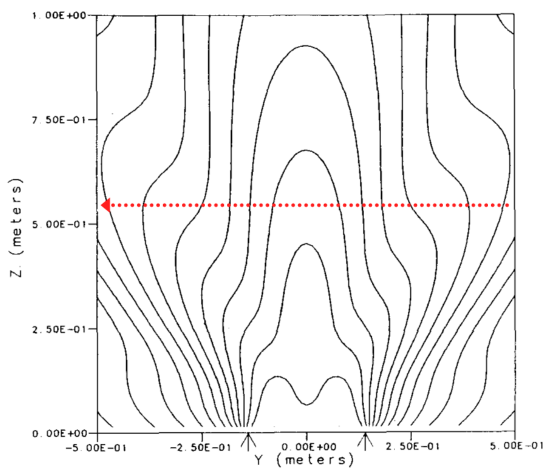
To learn about the effect from near and far fields without spending excessive time measuring in the chamber, a study on the subject has been found. Another study with similar setup that examines the effect of antenna configuration and reflections was also found. These are presented below.

A Practical Example - Near Field Regions

An article named ”Near-Field Patterns from Pyramidal Horn Antennas: Numerical Calculation and Experimental Verification” (Don W. Metzger, 1991) presents extensively calculated radiation plots from a horn antenna with aperture 36,7 x 26,3 cm and verified the results with experiments. The size is approximately the same as of this thesis antennas, making these results of interest to in this thesis.

In Figure 14 and Figure 13 below, the results of theoretical calculations show a pronounced main lobe at a distance of 1 m. The correction factor “a=1” is to accommodate for flaring of the horns aperture. The parameter “a” was varied between (0, >1) and the calculated results with “a=1,25” corresponded best to the experimental results. The lines in Figure 14 and Figure 13 represent +0,2 dB contour steps, and the frequency is fixed at 2,5 GHz in the entire study.

The calculated distance to the Fresnel region, using equation (8) and the diagonal of the horns aperture as its largest dimension, was 0,54 m.



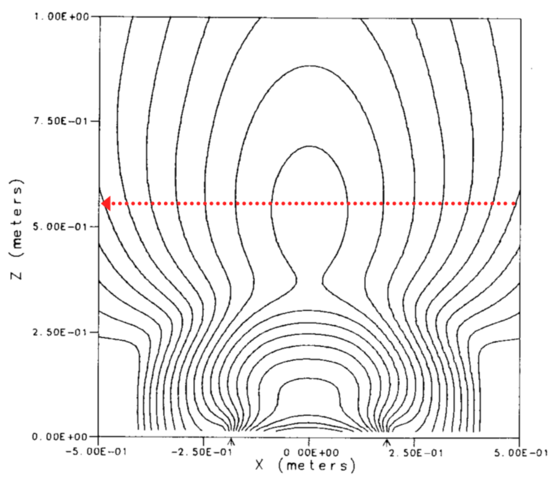


Figure 13: Theoretical radiation plot H-plane – (Don W. Metzger, 1991)

Figure 14: Theoretical radiation plot E-plane - (Don W. Metzger, 1991)

Using equation (9) to find the distance to the Fraunhofer region using the diagonal of the horns aperture as its largest dimension the results in 3,40 m. The red dotted lines in Figure 14 and Figure 13 above represent the boundary between reactive near field to radiative near field, Fresnel region. It intersects the contour steps that begin to form the far field radiation pattern. From this the conclusion is drawn that the field within the radiating near field Fraunhofer region is geometrically close to what is expected from the far field, especially since the setup at Ericsson is going to be greater than 1 m.

Another Practical Example – Distance Between EUT and Antenna

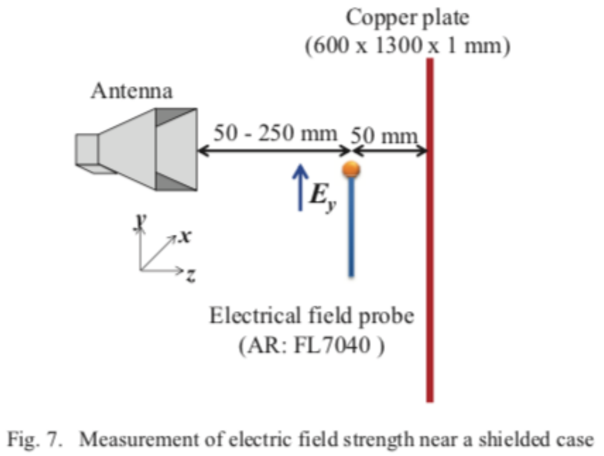


Figure 15: Test setup in the study from (Kazuhiro Takaya, 2016).

The article "Study on Test Distance Between EUT and Antenna for Radiated Immunity Test in Close Proximity to Equipment" (Kazuhiro Takaya, 2016) presents experimental results for testing radiated immunity with different antennas and a perfect reflector in copper behind the UFA. The setup is quite different from the thesis setup with respect to sizing and reflective background versus dampening cones.

The focus of the "Study on Test Distance Between EUT and Antenna for Radiated Immunity Test in Close Proximity to Equipment" is smaller products such as cell phones and are to be tested in a very specific way: antenna very close to the EUT, a small UFA and a total reflective area behind it, illustrated in Figure 15. Therefore, the setup is not similar to the experiments in this thesis however, the report demonstrate a phenomena that can explain reflections during the experiment in the thesis.

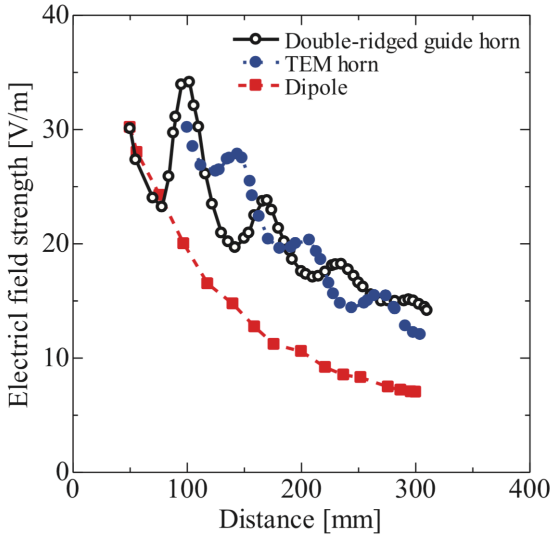


Figure 16: E-field reflections from copper plate backing during test - (Kazuhiro Takaya, 2016)

Figure 16 below shows the experimental results from having the different antennas at 300 mm distance from the reflective copper backing plate. The distance of the probe is varied from 50 mm to 250 mm from the antenna on the same axis of the antenna beam direction. The frequency of the test is 2,437 GHz driven with constant power. The near field of the antennas is 100 < near field < 200 mm. As seen in Figure 16, the electric field strength decreases inversely to the radius square just as theory states. However, a phenomenon arises for the TEM horn and Double-ridged guide horn that the dipole antenna did not generate. The author describes that these phenomena are arising because of the copper backing plate and large area of horn antenna. Indicating some sort of standing reflection between the horn and reflective copper plate. The peak-to-peak distance between fluctuating electric field strength peaks is approximately four wavelengths, 50 mm.

A small setup like this is not fully comparable to the test setup at Ericsson. The antenna dimensions are not stated. However, the distance to radiative near field is between 1/3-1/2 of the distance to the UFA, which is similar the setup at Ericsson. If the rear wall in Ericsson's chamber is highly reflective the Ericsson setup could produce this phenomenon in some minor extent.

Antenna Specific Properties

The manufacturer Schwarzbeck produces the two existing antennas for the test equipment, their model names are BBHA9120J & BBHA9120B. BBHA is an abbreviation for "Broad Band Horn Antenna". To understand the properties, possibilities and limitations of these antennas, the datasheets of them are studied for the parameters listed above and compared between each other.

BBHA9120J **-** (Schwarzbeck Mess - Elektronik, n.d.)

Physical Dimensions

435 * 680 * 440 mm (Width * Length * Height).
The largest dimension "D" of the antenna face is the hypotenuse of the aperture, 50 cm.

Using formula (8) and (9) the distance to the Fresnel and Fraunhofer regions for both the lowest (1 GHz) and highest (6 GHz) frequencies that will be used can be calculated. Results of the calculations:

- Distance to Fresnel region at 1 GHz = 0,40 m
- Distance to Fresnel region at 6 GHz = 1,0 m
- Distance to Fraunhofer region at 1 GHz = 1,7 m
- Distance to Fraunhofer region at 6 GHz = 10 m

This shows that at all relevant frequencies the UFA will be in the Fresnel region, as stated earlier under "A Practical Example – Near Field Regions". Hence calculations of fields should be comparable to the practical work in this thesis. However, when drawing conclusions from (Y. Rahmat-Samii, 1995), it should be stated that the experiments at Ericsson will be closer to the boundary of near/far field than the reactive/radiative near field boundary. In other words, on the verge of experiencing the far field geometrically.

Bandwidth

Specified frequency range 0,8 – 6,2 GHz.
Usable frequency range with acceptable VSWR <2,3. 1 - 6 GHz.

According to its specification of frequency interval, this antenna is sufficient for its use between 1 – 6 GHz.

Gain

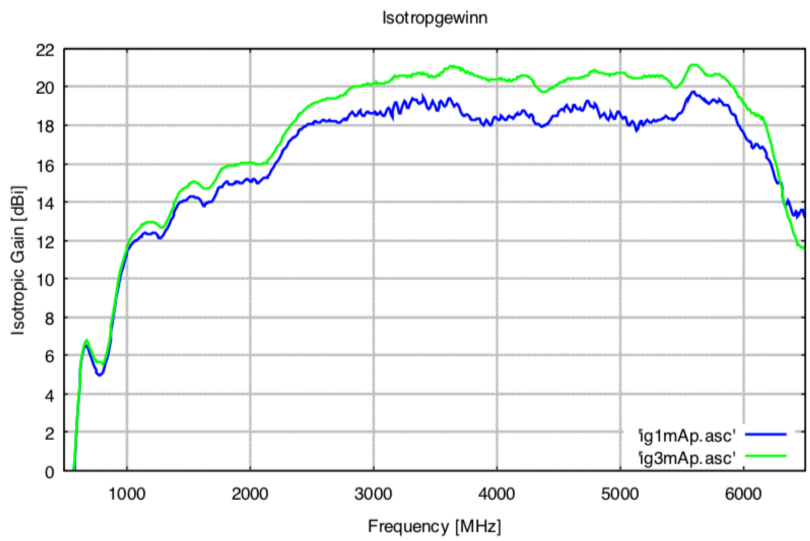


Figure 17: Gain over frequency for antenna BBHA9120J - (Schwarzbeck Mess - Elektronik, n.d.)

The gain of the antenna presented in Figure 17 shows that the general gain level between 3,0 – 6,0 GHz lies at 20 dB. Below 3,0 GHz it is closer to 12 dB, a difference of more than 6 dB which requires more than four times the power in comparison to generate the same field. This is also seen in the amplifier setup of EMC Rack 2 where the power amplifiers for 1,0 – 3,3 GHz is four times more powerful than the amplifier for 3,3 – 6,0 GHz, 400 W versus 100 W.

VSWR

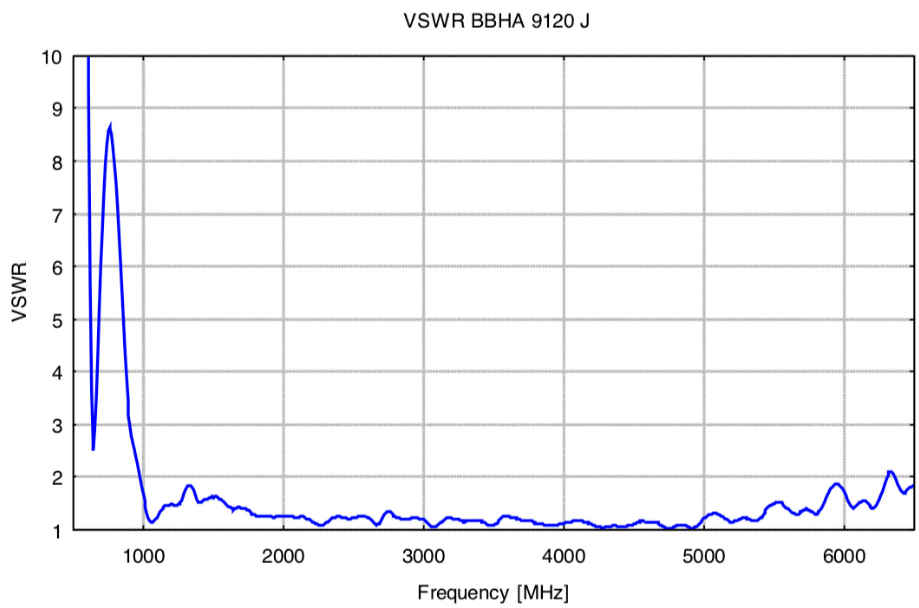


Figure 18: VSWR over frequency fro antenna BBHA9120J - (Schwarzbeck Mess - Elektronik, n.d.)

The VSWR shown in Figure 18 above displays no problematic areas that reach up to a value of 6 in our interval of interest between 1 – 6 GHz where the amplifiers would start to fold back power to avoid damage.

Beamwidth

Frequency [GHz]	Half-Power Beamwidth E-Plane [deg]	Half-Power Beamwidth H-Plane [deg]
0.8	48.3	48.3
1.0	40.8	40.2
1.5	29.5	27.1
2.0	25.8	23.4
2.5	18.2	16.2
3.0	18.1	14.0
3.5	16.2	12.2
4.0	13.1	12.5
4.5	13.4	13.2
5.0	12.2	16.4
5.5	11.6	18.4
6.0	11.4	13.8

Figure 19: Decreasing beamwidth with frequency for antenna BBHA9120J - (Schwarzbeck Mess - Elektronik, n.d.)

The specified HPBW in Figure 19 decreases with increasing frequency. This same pattern is shown for the -6 dB beamwidth. Hence the highest frequency this antenna will be used at is of interest.

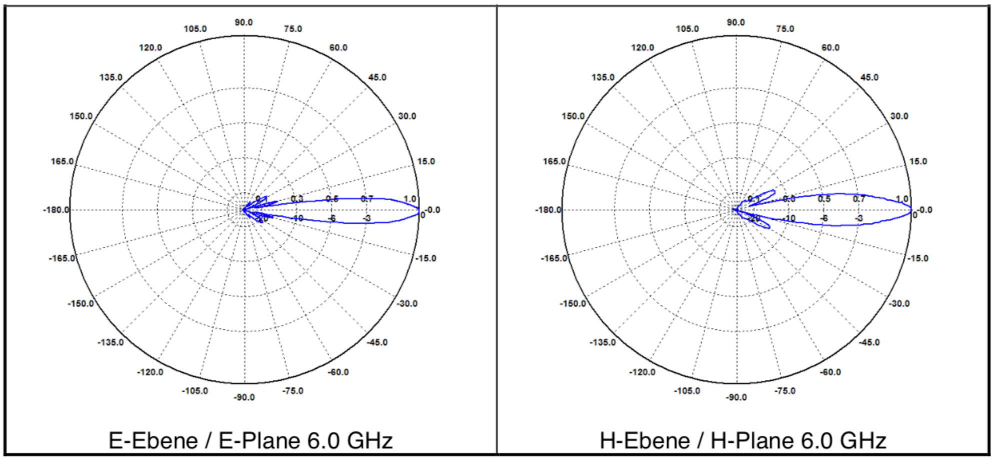


Figure 20: Beamwidth at 6 GHz for antenna BBHA9120J - (Schwarzbeck Mess - Elektronik, n.d.)

In Figure 20 the gain lobe at 6 GHz is shown. It displays that this antenna has a very narrow lobe at -6 dB, and beamwidth angles of:

E-plane: ±7 relative max position. 14-degree opening angle.
H-plane: ±9 relative max position. 18-degree opening angle.

The difference in beamwidth angle between E- and H-plane is relatively small and therefore and it could be assumed that the gain lobe is circular with a -6 dB beamwidth of 14 degrees at 6 GHz. 7 degrees is smaller than 9 degrees and therefore the most difficult case for the of the two.

Enclosing the UFA

Calculating the distance D between antenna and UFA using equation (7) and an antenna beamwidth of 14 degrees results in D=5,76 m. The antenna needs to be placed at a distance of 5,76 m away from the UFA to fully enclose all points of it within the -6 dB beamwidth. This is problematic since a distance of over 3,50 m is not obtainable in the chamber. It is not possible to illuminate a 1,0 x 1,0 m UFA with this antenna as the beamwidth narrows with increasing frequency.

Power Handling

The power handling of the antenna can be limited by material heating or arcing due to high voltage. In this specification the limiting factor is the antenna connector. The model available has the classical N-connector and is thus specified to 1 kW @ 1 GHz which is more than twice our amplifiers max output power. The antenna can not be harmed by any power levels obtainable with this test equipment.

(Schwarzbeck Mess - Elektronik, n.d.)

BBHA9120B (Schwarzbeck Mess - Elektronik, n.d.)

Physical Dimensions

182 * 272 * 128 mm (Width * Length * Height)
The largest dimension "D" of the antenna face is the hypotenuse of the aperture 21,5 cm.

Using formula (8) and (9) the distance to the Fresnel and Fraunhofer regions at the lowest (1 GHz) and highest (10 GHz) specified frequency can be calculated. Results of the calculations:

- Distance to Fresnel region at 1 GHz = 0,11 m
- Distance to Fresnel region at 10 GHz = 0,36 m
- Distance to Fraunhofer region at 1 GHz = 0,31 m
- Distance to Fraunhofer region at 10 GHz = 3,1 m

This shows that at all relevant frequencies 1 – 10 GHz the UFA will be in the Fraunhofer region when placed a distance >3,1 m from the antenna. For distances <3,1 m theory should be accurate enough as long as the distances are >0,5 m which is much less than what will be tested.

Bandwidth

Specified nominal bandwidth 1,5 – 10 GHz.
Specified useable bandwidth 1 - 10,5 GHz.

According to its specification of frequency interval, this antenna is sufficient for is 6 – 10 GHz.

Gain

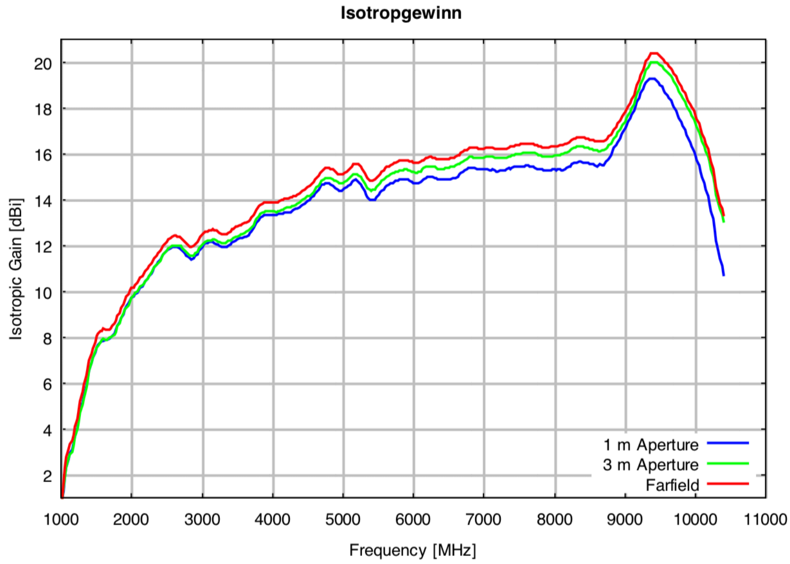


Figure 21: Gain over frequency for antenna BBHA9120B - (Schwarzbeck Mess - Elektronik, n.d.)

The gain of the antenna, presented in Figure 21 shows a steady level of 16 dBi in the interval of interest (6,0 – 10,0 GHz) except for a peak at 9,5 GHz that is favourable.

VSWR

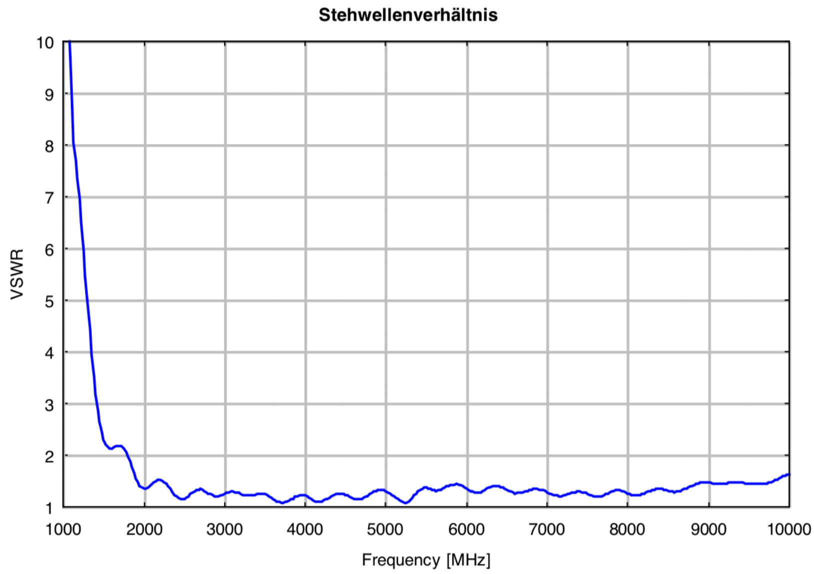


Figure 22: VSWR over frequency for antenna BBHA9120B - (Schwarzbeck Mess - Elektronik, n.d.)

The VSWR shown in Figure 21 above displays no problem areas with high VSWR in our interval of interest between 6,0 – 10 GHz where the Bonn amplifier possibly could take damage.

Beamwidth

Frequency	- 3 dB Beamwidth E-plane	- 3 dB Beamwidth H-plane
GHz	°	°
1	91.3	68.3
1.5	68.1	56.8
2	54.3	50.3
3	35.0	41.6
4	28.0	33.7
5	24.7	25.3
6	21.9	22.8
7	20.0	20.7
8	26.3	17.8
9	21.1	15.1
10	13.0	24.0

Figure 23: Decreasing beamwidth with frequency for antenna BBHA9120B - (Schwarzbeck Mess - Elektronik, n.d.)

The specified HPBW in Figure 23 decreases with increasing frequency. This same pattern is shown for the -6 dB beamwidth.

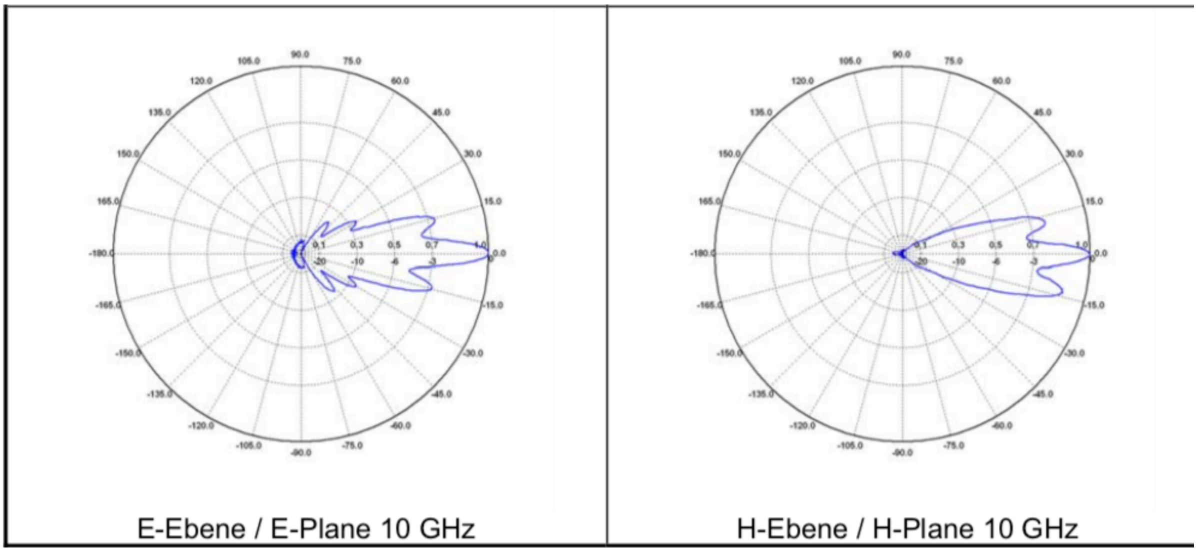


Figure 24: Beamwidth at 10 GHz for antenna BBHA9120B - (Schwarzbeck Mess - Elektronik, n.d.)

The narrowest lobes are read off at 10 GHz in Figure 24. Since all points should fulfil the uniformity demand, the angles are read where the gain lobes crosses 6 dB. For this antenna the -6 dB beamwidth angles are:

E-plane: ±21 relative max position. 42-degree opening angle.
H-plane: ±21 relative max position. 42-degree opening angle.

Note that both of these lobes have dips between full gain and 21 degrees. These do not drop below -6 dB and hence they lie within the uniformity demand.

The difference in beamwidth angle between E- and H-plane is none and therefore the assumption that the gain lobe is circular with a -6 dB beamwidth of 42 degrees at 10 GHz is made.

Enclosing the UFA

Calculating the distance D between antenna and UFA using equation (7) and an antenna beamwidth of 42 degrees results in D=1,84 m. The antenna needs to be placed at a distance of 1,84 m away from the UFA to fully enclose all points of it within the -6 dB beamwidth.

Power Handling

This antenna is also limited by the N-connector as described above in “BBHA9120J Power Handling”, except BBHA9120B is specified at 300 W continuous power, which is six times the available power of 50 W within this interval.

(Schwarzbeck Mess - Elektronik, n.d.)

Comparison of the two antennas

The two antennas were chosen to operate in two different intervals, from 1 - 6 GHz and 6 - 10 GHz. These intervals correspond to the two test levels and also to the operating ranges of the amplifiers. The amplifiers have been adapted to the antennas, they match the antennas frequency ranges and gain levels. If an antenna would be used outside these intended intervals, then a change of cabling to connect the correct amplifier to respective antenna would have to be performed. This would increase testing time and wear on connectors and cables (bending), effectively reducing the signal path mechanical lifespan by half. Hence, deviating from this engineered setup by testing other antenna/frequency combinations is not relevant.

1-6 GHz - BBHA9120J – Larger antenna

This antenna has generally 4-6 dB higher gain than the smaller antenna. The distance to the Fresnel region is going to be shorter than to the UFA, however the Fraunhofer region will wander from 1,6 m in between the antenna and the UFA to 10 m which is outside the chamber as the frequency is swept from 1 – 6 GHz. Hopefully, this will not cause a possible lack of performance in the higher end of the frequency interval.

6-10 GHz - BBHA9120B – Smaller antenna

For this antenna, all areas will be in the far field region, hence results closer to what is calculated in theory chapter “Performance” is expected. Because of this, and the fact that they overlap in usable frequency interval, it would be interesting to test this antenna down in the <6 GHz frequency span. From Figure 25 below that compares the gain curves and sees that BBHA9120B generally -6 dB lower gain than BBHA9120J, which would require four times the forward power to obtain the same E-field. However, because of its smaller size and considerably wider beamwidth it could possibly irradiate a larger UFA. As stated earlier in the report, this configuration would require a change in cabling or further installations of more relays in EMC Rack 2 hence it is not considered for this thesis.

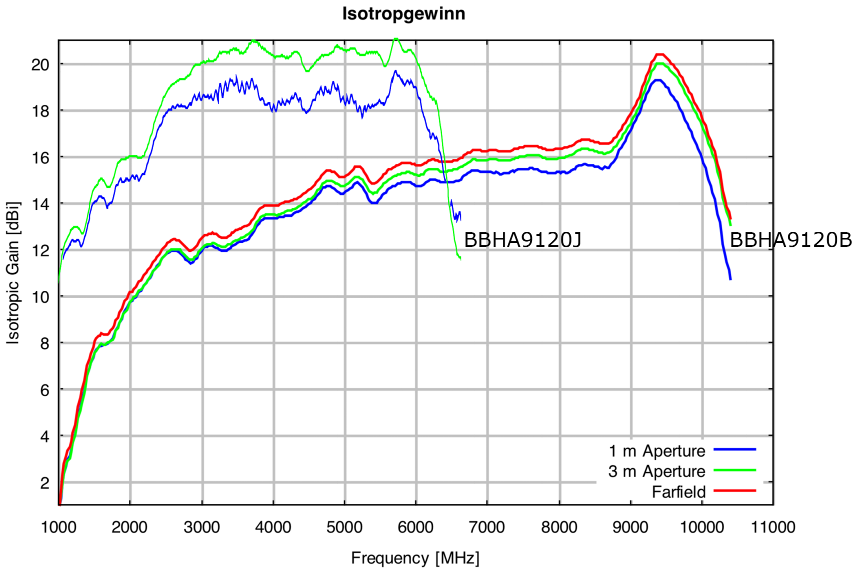


Figure 25: Gain over frequency comparison between antennas BBHA9120J & BBHA9120B - (Schwarzbeck Mess - Elektronik, n.d.) (Schwarzbeck Mess - Elektronik, n.d.)

Chamber

There are multiple parameters in the chamber and the test equipment that limits how a test can be performed and how reflections will occur, dampening surfaces etc. All relevant parameters to the probe and chamber are presented and investigated in this chapter.

<u>Probe and Interface Response Time</u>
Probe model: FL7218, AR RF/Microwave instrumentation
Specified frequency range: 2 MHz – 18 GHz
Specified E-field measuring level: 2-1000 V/m

The electric field measuring probe in the chamber is connected to the computer via an interface, which uses optical cabling to the probe inside the chamber. To obtain correct values, the probe and interface response time has to be shorter than the measuring time. In the datasheet of the probe (AR RF/Microwave instrumentation, 2007) it is specified that this combo of probe, interface and 100 m cabling return steady values after 20 ms. Hence the measuring time can confidently be set to >20 ms with only respect to the probe and interface.

<u>Chamber Response Time and Reflections</u>
Response time
The chamber resonance time from no E-field to a full E-field application from the antenna determines its response time and must be shorter than the measuring time. According to the consultant Per Isacsson, a fraction of a second, circa 100 ms should be enough (Isacsson, 2020)

From previous experience within Ericsson, the measuring time should not be less than 100 ms with respect to the probe and chamber.

Reflections
There are three different types of wall surface that the electric field can reflect on. See Figure 30. These surfaces are **Tiles, Tiles with dampening cones and Earthed steel floor.**

Tiles; Frankonia FrankoSorb F006 – ferrite tiles (Frankonia GmbH, 2013)

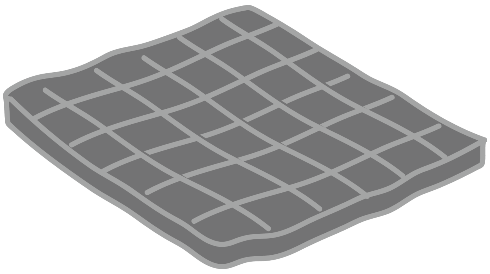


Figure 26: Illustration of Frankosorb F006 ferrite tile dampener

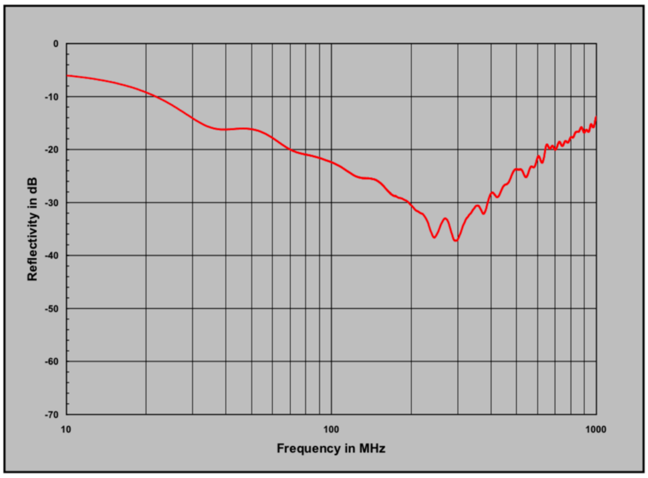


Figure 27: Reflectivity over frequency for FrankoSorb F006 ferrite tile dampener - (Frankonia GmbH, 2013)

The reflections of these tiles are specified in their datasheet with Figure 27. They are constructed to provide dampening in the interval 10 MHz – 1 GHz. This is below the frequency span of interest of this thesis and the specification does not define the reflectivity outside of 10 MHz – 1 GHz. These are placed on all surfaces except the floor under the antenna and the UFA.

Tiles + Cones; Frankonia Frankosorb H450-A2 (Frankonia GmbH, 2013)
Frankonia FrankoSorb H450-A2 includes the ferrite tiles described above together with four laminated cones on top. The cone construction is illustrated in Figure 32. These are specified to work from 30 MHz – 40 GHz.

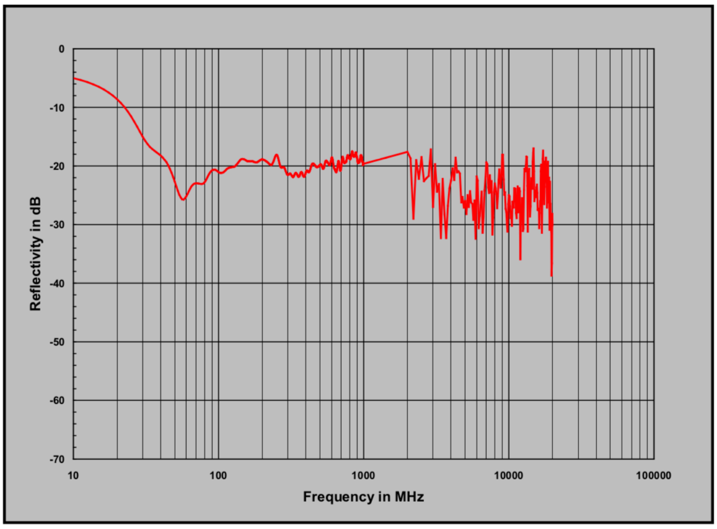


Figure 28: Reflectivity over frequency for Frankosorb H450-A2 cones and ferrite tile dampener combo - (Frankonia GmbH, 2013)

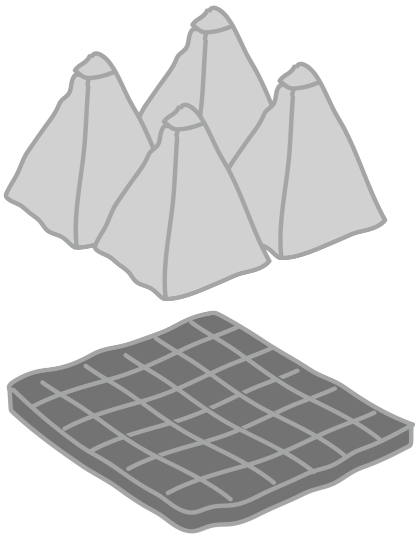


Figure 29: Illustration of Frankosorb H450-A2 ferrite tile and cone combination

From the specification in Figure 28 the reflectivity in the interval of interest for this thesis, 1 - 10 GHz is generally -20 dB.

Earthed floor

The entire floor is made out of steel, which is earthed. The floor is considered to be a good reflector due to its material. To decrease the reflections from the floor, extra cones can be placed on top of the floor.

Possible reflections

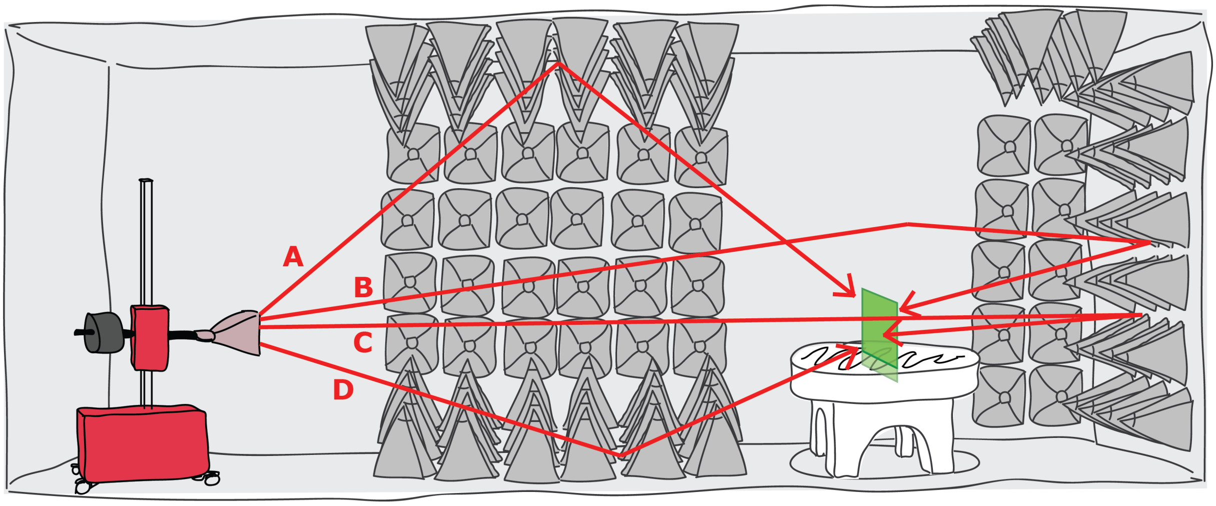


Figure 30: Possible E-field reflection paths in chamber, from antenna to UFA

There are many possible paths where reflections can occur and cause destructive interference. To fully calculate the effects of all reflections, an extensive computer simulation the size of another thesis would have to be performed. However, simplified analyses can provide a rough understanding and estimate which reflections are most problematic in the chamber and which shall firstly be avoided. Only direct reflections of the kind with incident angle that is equal to the reflected angle is considered. These reflections will travel through atmosphere and reflect on a surface and travel to the UFA. Hence two parameters that cause attenuation of the reflected wave are examined. Specified reflection loss from above and air attenuation below. They are then summarised.

Air attenuation of EM-waves in chamber

The air attenuation in atmospheric air is presented in Figure 31 below from The International Telecommunication Union, Recommendation P.676-9, Attenuation of atmospheric gases.

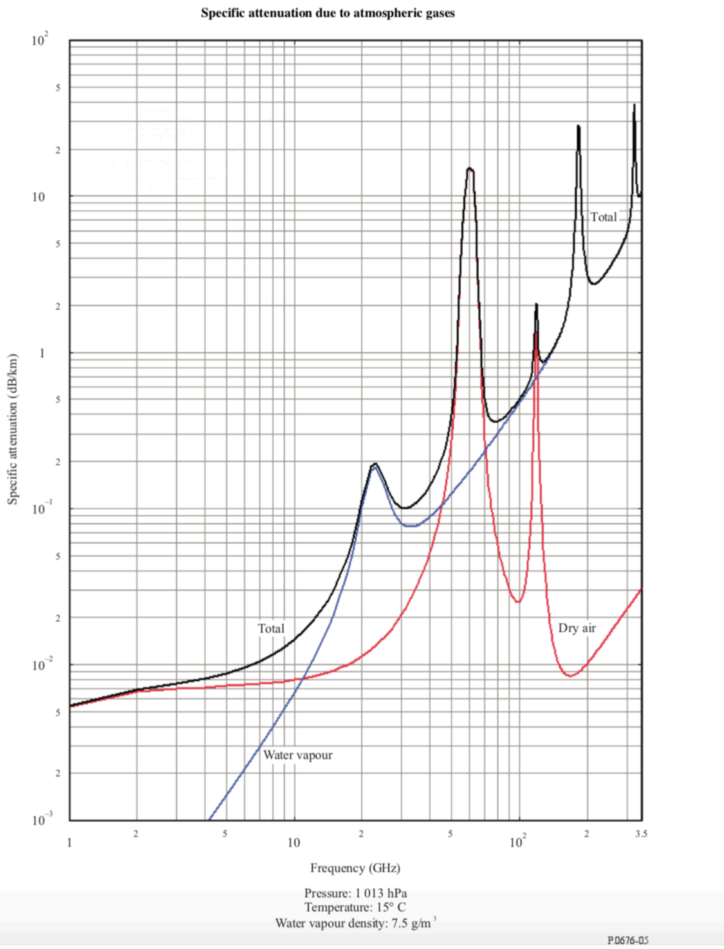


Figure 31: Air attenuation of electromagnetic waves - (International Telecommunication Union - Radiocommunication Sector, 2012)

The total specific attenuation for frequencies between 1-10 GHz is found that it is always less than 2*10^-2 dB/km. By converting to meters it is 2*10^-5 dB/m. The logarithm for power is defined as follows: (ARRL - Amateur Radio Relay League, 2007, p.44)

$$A = 10 * \log\left(\frac{P1}{P2}\right) \qquad (-) \qquad (10)$$

If equation (10) is reversed to calculate the logarithmic value of the ratio P1/P2 the percentage of lost power is obtained. Note the – sign in equation (12) that defines that power is lost.

$$\frac{P1}{P2} = 10^{\frac{A}{10}} \qquad (-) \qquad (11)$$

$$\frac{P1}{P2} = 10^{\frac{-0.00002}{10}} = 0.99999539 \ldots \qquad (12)$$

Less than a thousand part of a percent is lost through air attenuation. This loss is from now on considered negliable.

Summarized reflection losses

The case with 3,5 m distance of antenna to UFA is considered since it is the case with most wall/floor/ceiling area between antenna and UFA for reflections to hit. The antenna height is 1,0 m since it is the lowest height the Frankonia antenna tower can achieve. For simplification and symmetry reasons, the middle of the UFA is also considered to have a height of 1,0 m. Case C and D will be considered.

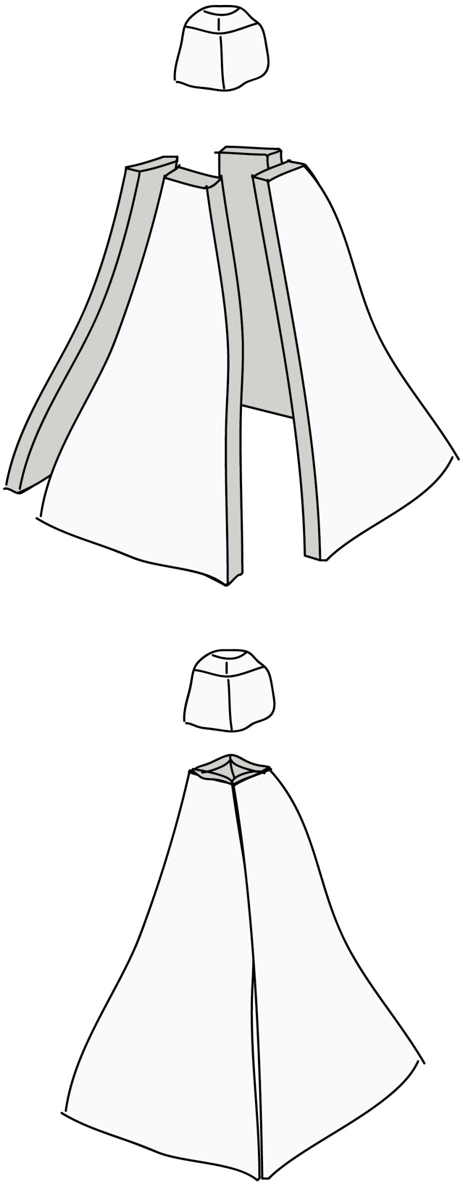


Figure 32: Frankosorb H450-A2 cone construction

Case C

Case C includes one reflection from the rear wall. Thus the level of the reflection is at least -20 dB compared to the original signal at the UFA. Not including the fact that the wave front from the antenna has a lower power density at the back wall than at the UFA. Also not including the standing reflection that will arise when the reflected wave travels back and forth between the wall behind antenna and wall behind UFA and attenuated at every reflection in between.

Furthermore, in case C there is another phenomena that can occur alike the "Another Practical Example – Distance Between EUT and Antenna" because of the cone construction. Since these cones are built in such a way as described in Figure 32 below, with compound sheets that are glued together with a thin plastic cup on top, there is a square left open at the tip of the cones. The square open area covered in plastic is 2-3 cm in dimension. Big enough for the wavelength of 1-10 GHz that is 30-3 cm to partially enter and reflect on only the tile and not cone. This will fail to attenuate the standing E-field wave between every adjacent wall couple in the chamber. This phenomena requires the incident E-field to enter at a straight angle to the wall, which limits the amount of possible apertures to enter to only a few behind the UFA. By previous experience from Per Isacsson, the phenomena occur mainly at significantly larger chambers (Isacsson, 2020)

Case A & D

For Case A & D there are three different possible paths for the reflections to occur at the floor, ceiling or walls, with the possibility of a symmetric addition of both walls. What differs these cases from C which is radiated in the maximum gain direction of the antanna, is with all simplifications the same, the angle from the antenna that the reflection is radiated will differ. Case A & D will exit with less gain from the antenna before reflecting on any surface and traveling to the UFA. The worst case will then be at low frequencies for both antennas due to their broader beamwidth at lower frequencies.

The time it takes for the signal to travel the extra distance is not enough to create a 180-degree shift in the wave and cause destructive interference. However, when the signal bounces on the floor with polarisation perpendicular to the surface, the signal reaching the area will be close to 180 degrees out of phase. This causes destructive interference. (Wallander, 1998).

Geometrical angles for reflections between antenna to UFA is calculated from the physical dimensions of the chamber and placement of antenna for the case with 3,5 m distance between the antenna and UFA with 0-degree offset angle. The loss in gain relative max gain is found in the datasheets of the antennas. Adding the negative gain to the reflection loss, the level of the reflection, relative to the level of transmitted signal level in forward direction is obtained. The results are shown in Table 1 below.

	Gain from antenna relative max gain (dB)	Reflection loss tiles + cones (dB)	Level at UFA relative original signal level (dB)
BBHA9120J @ 1 GHz			
Floor reflection: 30 degrees	-4	-20	-24
Wall reflection: 43 degrees	-7	-20	-27
Ceiling reflection: 49 degrees	-10	-20	-30
BBHA9120B @ 6 GHz			
Floor reflection: 30 degrees	-6	-20	-26
Wall reflection: 43 degrees	-15	-20	-35
Ceiling reflection: 49 degrees	-17	-20	-37

Table 1: Estimate of reflection levels from floor, walls and ceiling

Comparison of reflection C vs A & D

The strongest reflection to meet the UFA will originate from the rear wall at around -20 dB. The next strongest reflection will be coming from symmetrical sidewall reflections at two times -27 dB reflections. Adding the E-field of the two increases its magnitude with +6 dB, hence the symmetrical level will be -21 dB, only a decibel less than the rear wall reflection.

From this it is concluded that the worst direct reflections will originate from the rear wall as well as the symmetrical wall reflections. Disrupting the symmetry in the chamber and letting the rear wall reflect the waves back at an angle can reduce the rear wall reflection and addition of symmetrical wall reflections. However, this measure can only decrease the worst peaks from reflections since no aggressive angles can be obtained in this relatively small chamber.

Modelling of Test Equipment Setup
To examine if the test equipment is underpowered, the forward power required to illuminate a 0,5 x 0,5 m UFA at a 3,5 m distance is calculated. The required field in V/m is known from earlier chapter "standards" and by using known parameters of the signal path the required amplifier forward power is obtained. Every contribution in calculation from respective part of the signal path is presented below.

An illustration of the signal path is shown in Figure 33 below. The units and measurements are stated at the bottom to clarify an overview of the calculations.

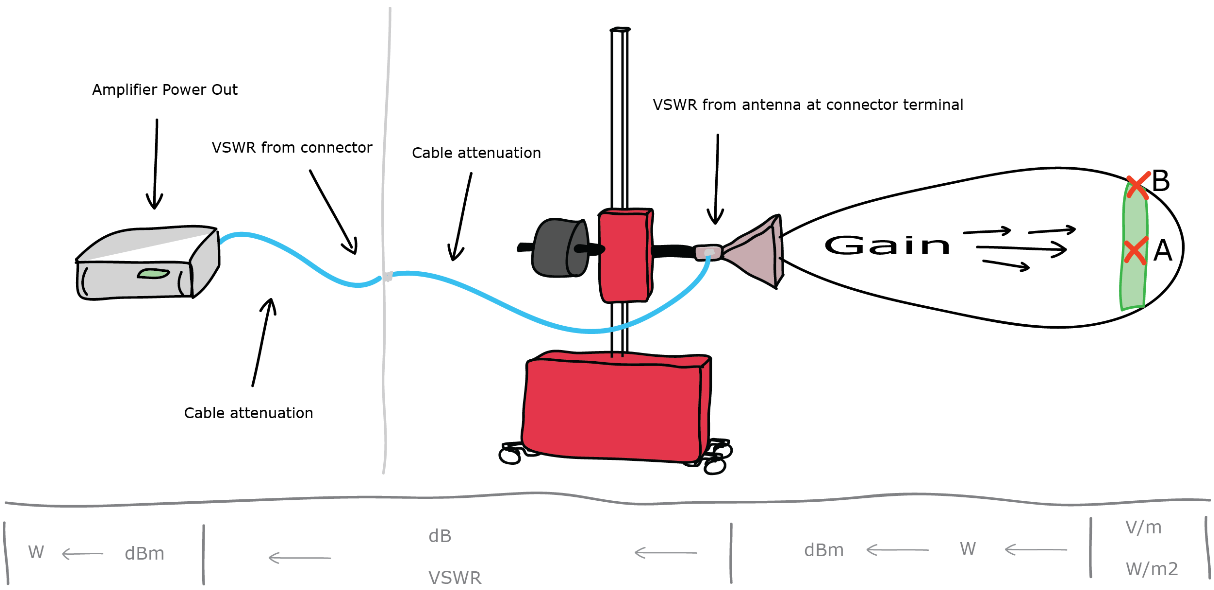


Figure 33: Illustration of signal path of test equipment setup, from PA to UFA

<u>E-field at UFA</u>
Starting at point B in Figure 33 and moving left, it has to fulfil the lowest demand of electric field 54 V/m.

<u>Input Power at Antenna</u>
Gain
Point A, which lies on the beam axis of the antenna, a distance 3,5 m from the antenna will differ from point B with a correction factor "C" that compensates for the difference in antenna gain between A and B. The E-field level at A can then be calculated using logarithm for voltage (13)

$$A = B * 10^{\frac{C}{20}} \quad (V/m) \tag{13}$$

For the "worst" case scenario the correction factor can reach values up to "C=6 dB", which is equivalent with the (0,+6dB) uniformity demand. C varies because it is the magnitude difference between point A and B for every frequency. These values of C is obtained from the specification sheet of both antennas for every specified frequency by reading the difference in gain between 0 degree opening angle and half of the beamwidth angle required to cover the UFA. An example is shown below in Figure 34. Since this value can be obtained for both

horizontal and vertical polarization, the larger difference value that will give a higher output power level in the end result was chosen for conservative calculations.
The angle that the gain correction is obtained from is the angle covering a 0,5 x 0,5 m UFA at a distance 3,5 m away from the antenna by inverting equation (7). The angle is 5,768≈5,8 degrees in this case.

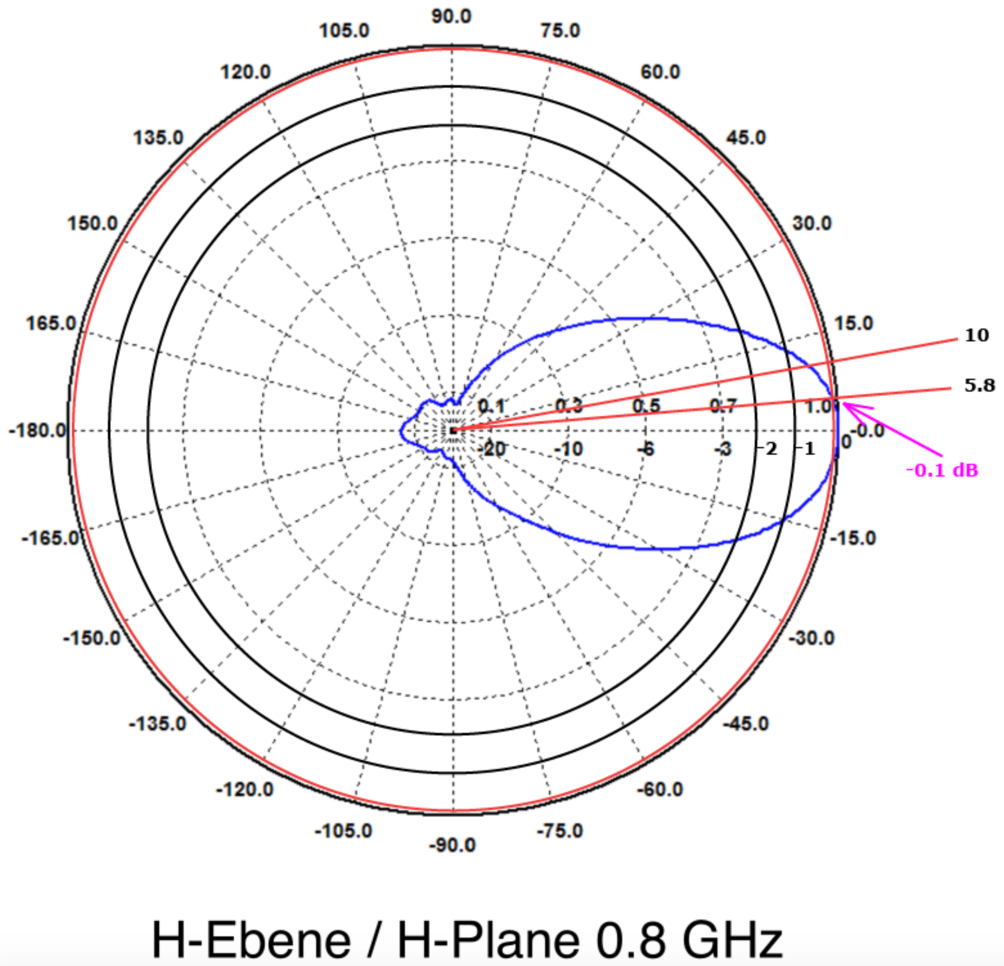


Figure 34: Acquiring difference in gain between point A and B from antenna gain lobe plot in antenna datasheet

As seen in Figure 34 above the angle of 5,8 degrees is drawn radially from the centre that represents the antenna position and the value of the gain where it crosses the blue gain lobe is read off the gain axis. In this case checking the correction factor C for BBHA9120J at 0,8 GHz where it has its widest gain lobe, there is almost no difference between point A and B, only a magnitude of 0,1 dB.

This procedure was repeated for all specified gain lobes in the antenna specifications and was then plotted and curve fitted in Excel with a sixth-order parabola. The results are shown in Figure 35 and Figure 36 below.

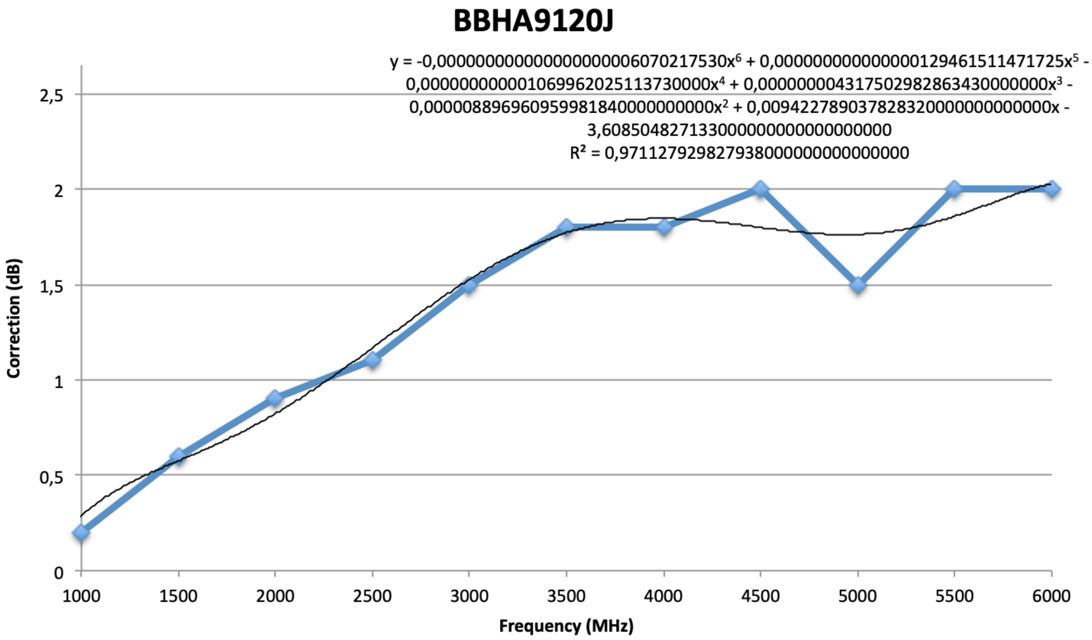


Figure 35: Correction constant for antenna BBHA9120J

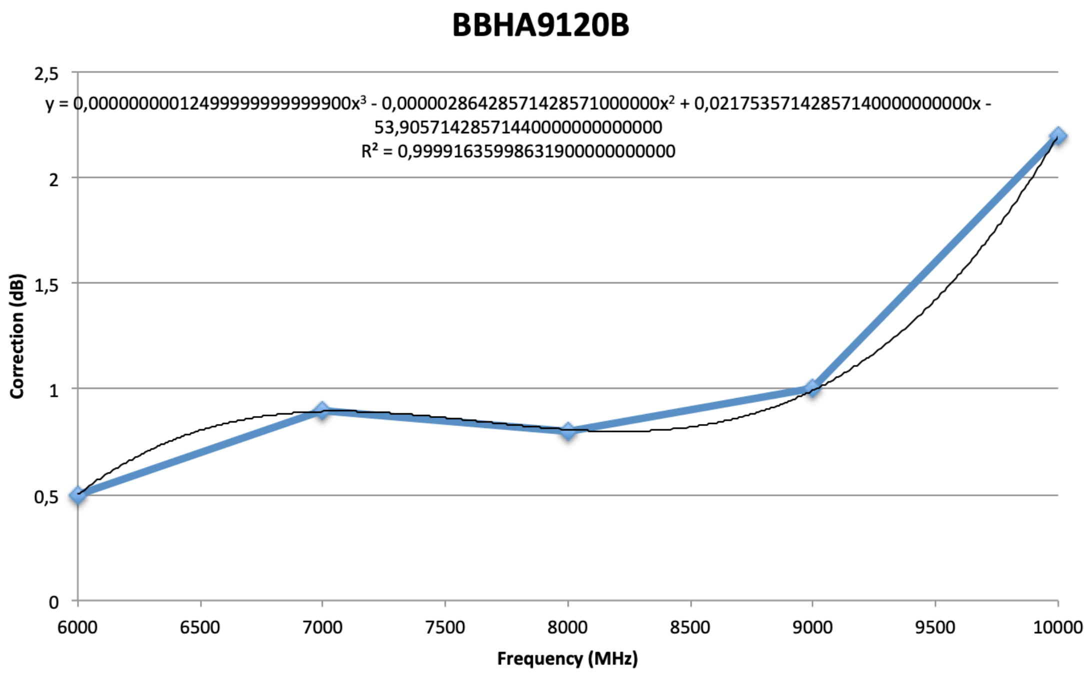


Figure 36: Correction constant for antenna BBHA9120B

Distance between antenna and UFA

The power radiated from the horn antennas will radiate in a volume and the power density will decrease with distance. The decrease is defined from the isotropic radiator multiplied with the horn antenna gain.

By setting the power equation with U=A and Z = 120 π (impedance of air) equal to the power input to the isotropic antenna, multiplied with the horn antenna gain, divided by the area it radiates over the following equation is obtained:

$$\frac{(A)^2}{120\,\pi} = \frac{P_{radiated} * G_{antenna\ gain\ (dBi)}}{4 * \pi * r^2} \qquad (W/m^2) \qquad (14)$$

Solving for P

$$P_{radiated} = \frac{(A)^2 * r^2}{30 * G_{antenna\ gain\ (dBi)}} \qquad (W) \qquad (15)$$

(Sevgi, 2017, p.114)

Using equation (10) to transform the gain from dBi to fraction:

$$P_{radiated} = \frac{(A)^2 * r^2}{30 * G_{antenna\ gain\ (dBi)}} = \frac{(A)^2 * r^2}{30 * \ 10^{\frac{G_{antenna\ gain\ (dBi)}}{10}}} \qquad (W) \qquad (16)$$

All values of antenna gain for both antennas are given in 1% logarithmic steps in their respective datasheet and from this information, this calculation will be executed at every 1% logarithmic step on the interval 1-10 GHz.

VSWR at Antenna

The Voltage Standing Wave ratio (VSWR) is defined earlier in equation (2) and to calculate the power reflected from it, the equation is inverted and the expression becomes:

$$|\Gamma| = \frac{VSWR - 1}{VSWR + 1} \qquad (-) \qquad (17)$$

The reflected power is then proportional to the square of the reflection coefficient (Bevelacqua, 2009)

$$Reflected\ power\ (\%) = 100 * |\Gamma|^2 = 100 * \left(\frac{VSWR - 1}{VSWR + 1}\right)^2 \qquad (18)$$

Assuming that all power that is reflected will be lost, will facilitate further calculations. However, in reality the power that is reflected will reflect back and forth on the line and every time it travels along the line it attenuates in heat until it reaches a connector and some of it gets transmitted and the rest reflected back. Every time it reaches the antenna, part of it will radiate and the same percentage of reflected power will continue to bounce back and forth again. Hence assuming all the reflected power is lost will result in a slightly higher need of amplifier power, continuing to perform conservative caluculations, assuming that the VSWR and cable attenuation in the system is fairly low. (Achillie, 2017).

The VSWR of the antennas are not given in tabular form but presented as a typical value and in graphical format. In this model the typical value will be used.

VSWR BBHA9120J = 1,3
VSWR BBHA9120B = 1,5

(Schwarzbeck Mess - Elektronik, n.d.) (Schwarzbeck Mess - Elektronik, n.d.).

VSWR at Through Wall Connector
The wall connector has a manufacturer specified VSWR curve that is displayed in Figure 49 as VSWR=1,03 + 0,01 * f (f in GHz) (Huber & Suhner, 2020).

Line Attenuation
The value of line/cable attenuation is frequency dependent and certain values are stated in the datasheet of the cables (Rosenberger, 2014). These are plotted in Excel and fitted with a well-fitting trend line (R value close to 1) to obtain values for all frequencies. Line 1 from the amplifier is 0,5 m long and line 2 to the antenna is 1,2 m long.

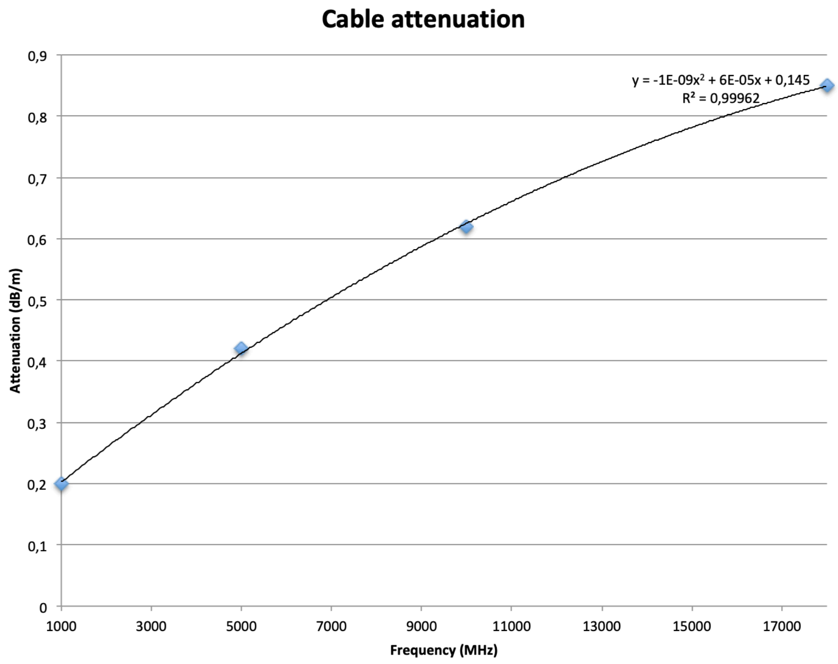


Figure 37: Cable attenuation of UFB293C [dB/m]

Power Level at Amplifier

With all this data, the required power from the amplifiers can be calculated and plotted. All remaining steps of the problem can now be solved in decibels according to equation (19) and then converted to watts at the amplifier using equation (10).

$$\begin{aligned} Amplifier\ power\ (dBm) &= Line\ attenuation, line\ 1\ (dB) \\ &+ Reflected\ power\ at\ wall\ connector\ (dB) \\ &+ Line\ attenuation, line\ 2\ (dB) \\ &+ Reflected\ power\ at\ antenna\ (dB) \\ &+ Antenna\ fwd\ power\ (dBm) \end{aligned} \qquad (19)$$

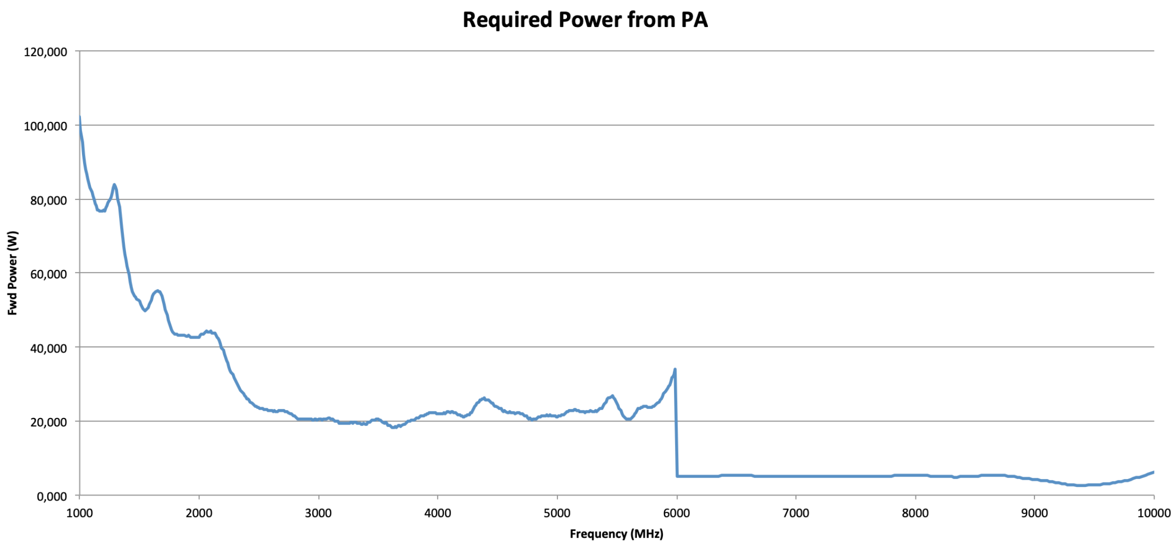


Figure 38: Performance analysis, required output power for test equipment setup, 3,50 m 0,5 x 0,5 m UFA

The calculation isperformed in Excel and the result for the needed power is displayed in Figure 38 above. It show that the amplifier levels are above what is needed and hence the test levels should be reachable with the antennas placed at 3,5 m distance from the UFA. The beamwidth of the antennas will cover all points of the UFA. Note that no reflections were taken into account in this model.

3 Method

In this chapter, all information regarding the experimental measurements will be explained. The experimental measurements conducted measure the obtainable levels of E-field at any point in the chamber, for both antenna polarisations where the field probe is placed. By placing the probe in the shape of an UFA, it can be evaluated if it is possible to calibrate an area of the tested size. All possible configurations of antenna placements in the chamber are defined, as well as how the test setup is configured with regards to hardware and software.

Experimental measurements were initiated with 1-6 GHz since there was no amplifier available for testing 6-10 GHz, however a loan amplifier for 6-10 GHz arrived halfway throughout the tests. The UFA size primarily measured was 1,0 x 1,0 m with 9 measuring points since it was the size that Ericsson first specified when the test equipment was ordered. Since this was found unachievable, the smaller size 0,5 x 0,5 m was measured on the turning table with the best antenna position found.

3.1 Parameters to test

Placement of Antenna - Distance to UFA
Varying the distance between antenna and UFA will show at what distance the antenna gain lobe will cover the entire UFA as described in the theory section. Distances tested were the nearest extreme, middle position and furthest extreme, 2,20/3,0/3,50 m.

Utilization of Extra Dampening Cones
Introducing extra dampening cones in the chamber will reduce the reflections according to theory. The extra dampening cones were placed in two positions, on the floor under the UFA and on the floor behind the UFA. Two points were tested to verify the effect of this measure.

Placement of Antenna - Angular Displacement
An offset in the angle of attack between the antenna and UFA was introduced to reduce symmetrical wall and rear wall reflections as stated in theory. The antenna was moved closer to the side of the chamber in the direction closer to the through wall connectors to allow a shorter signal path, and directed towards the centre of the UFA. The geometrically minimum test angle was 0 degrees, medium 10 degrees and maximum available was 15 degrees at 3,50 m distance to UFA.

Placement of UFA - Distance to Back Wall
With all the previous placements of antenna already placed at optimum and satisfying results for 1,0 x 1,0 m UFA were still not obtained, a movement of UFA from the turning table was tested. This compromises the use of the turning table that is essential for testing the EUT from different faces. The largest distance obtainable between antenna and UFA was 4,30 m that would just fit all cabling connected to the EUT during a test.

Antenna height
This parameter was neglected since the antenna needs to be positioned at a height equal to the centre of the UFA to cover it within the gain lobe, the UFA is specified to begin at 80 cm above ground. There was no results from the previous measurements that proved points above or below the centreline of the antenna was favourable. The static height of the antenna was control measured with a ruler to assure correct height is registered in the control software.

Figure 42 displays how the antenna placements in the chamber were measured. In the pictured example, the antenna is placed at 3,50 m from the UFA at 15 degrees offset. Note that the distance 3,50 m is not measured radially from the UFA, so in reality the distance is longer by a factor cosine of the angle.

In Figure 39 below, there are two white strips of electrical tape in the floor that marks the 3,00 and 3,50 m distance to the UFA. The tape is marked with degree marks so that the measuring tape can be aligned on the floor and show respective angle, 0, 10, 15 degrees towards the UFA. Perpendicular to the white tapes, a ruler can be placed to measure the exact distance to the UFA. All measurements are read from the bullet weight hanging from the centre of the tip of the antenna.

Figure 39: Physical measurements of antenna position, offset angle and distance to UFA

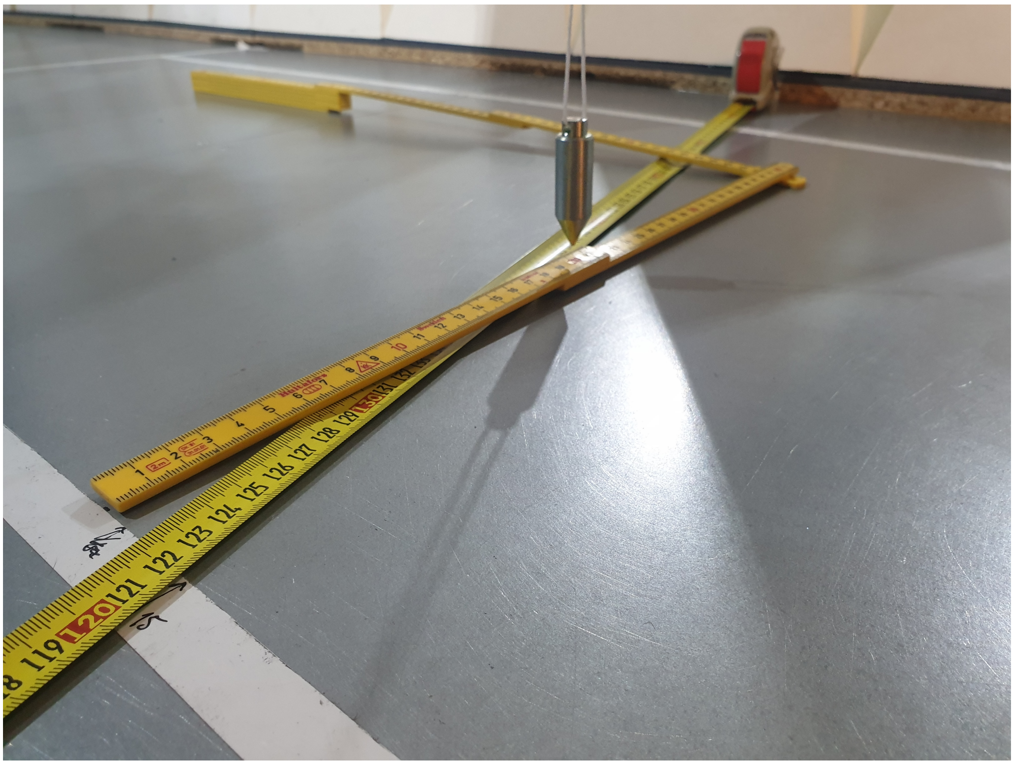


Figure 40: Close-up of rulers for measurement of antenna position, offset angle and distance to UFA

Table 2: Experimental measurements performed

Measurements	UFA Size			
Placement of Antenna - Distance to UFA 1-6 GHz	1,0 x 1,0 m	2,20 m	3,00 m	3,50 m
Utilization of Extra Dampening Cones 1-6 GHz	1,0 x 1,0 m	Underneath UFA	Behind UFA	
Placement of Antenna - Angular Displacement 1-6 GHz	1,0 x 1,0 m	0-degree	10-degree	15-degree
Placement of UFA - Distance to Back Wall 1-10 GHz	1,0 x 1,0 m	4,30 m		
Optimal placement 1-10 GHz	0,5 x 0,5 m	3,50 m, 15-degree		

3.2 Hardware setup for testing

All the measuring is monitored from and controlled by a computer outside of the chamber illustrated in Figure 42 and denoted control desk. All signal generators, amplifiers and control interfaces for every EMC test within the entire lab are coupled with Ethernet cabling to the computer. Hence all control and data acquisition is done in the computer with the software EMC32.

The test equipment in EMC Rack 2 is pictured in Figure 8 and consists of a signal generator that is controlled by the computer and drives the amplifiers which are connected to the RF-out connectors on the rack through a couple of power meters reading forward and reflected power. From these RF-outputs there is cabling entering the chamber. From the respective chamber wall connector, the antenna for the current frequency band is connected with another cable inside of the chamber. A simplified signal path is illustrated in Figure 33.

The ancillary equipment that is used for this test setup and multiple other EMC-tests is the chamber and E-field measuring probe. These are considered tools to execute radiated immunity testing and will not be examined further than their specifications. The chamber is of type semi-anechoic, which states that it is partly covered in dampening cones and has a grounded metal floor. The inside is isolated from E-fields outside of the chamber caused by nature and equipment in the vicinity. It is also designed to reduce reflections of E-field within the chamber. These physical properties suits its purpose very well with easy access to antenna and EUT. However a semi-anechoic will have more reflections compared to a full anechoic chamber due to less dampening materials such as cones inside of the chamber. It is ventilated to keep equipment inside cool, its placement within the black box lab also provides it with normal operating conditions with regards to temperature and humidity. It is also equipped with various feedthroughs such as AC & DC power supply, RF-connectors, Ethernet connectors, optical cabling etc. to allow for operation and measuring of equipment within the chamber. These are all parameters that can affect test results and measurements within the chamber. All of these feedthroughs are EMC-properly installed by the manufacturer and the recorded noise floor within the chamber is presented in Figure 41. The noise is always below 45 dBuV/m or 175 uV, which is considered completely insignificant compared to the levels in this thesis. Note the difference in noise level at 6 GHz, it is explained by a change in equipment signal path calibration during measuring. The noise floor in the chamber is comparable in magnitude to the internal equipment calibrations to correct for internal noise.

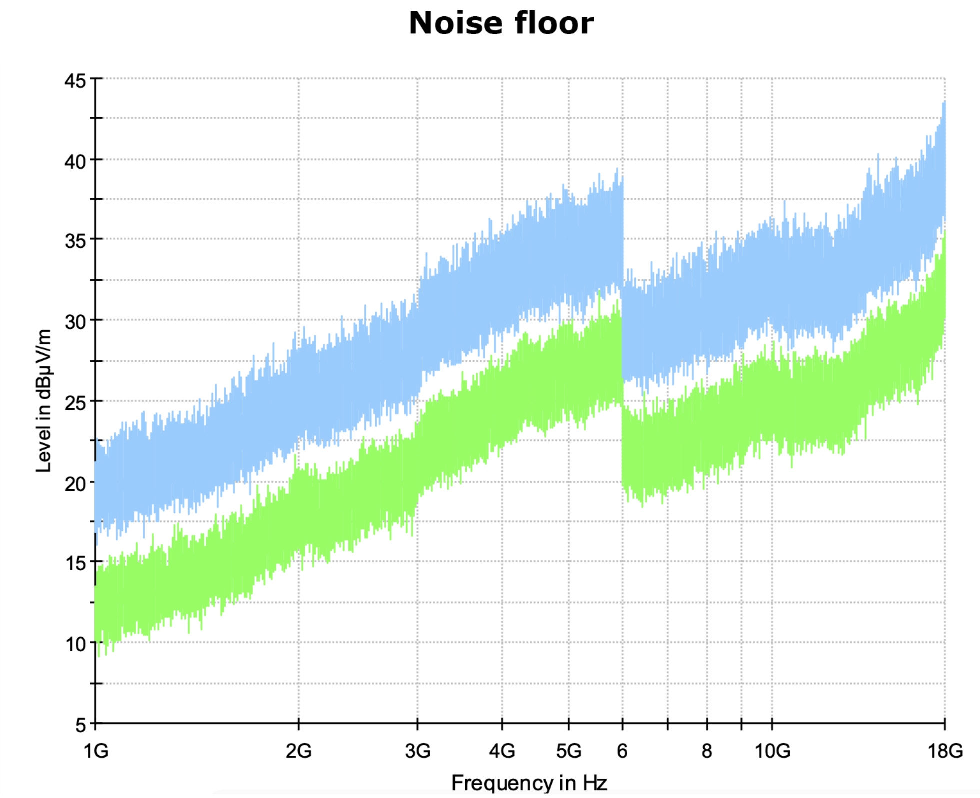


Figure 41: Electromagnetic noise floor in EMC chamber, 1-18 GHz

The field probe for measuring E-field magnitude operates through an interface that is placed in EMC Rack 1. It is connected to the computer with Ethernet cabling and is connected to the probe with optical cabling. The optical cabling is essential so that the use of the probe will not affect or be affected by the fields inside of the chamber. The probe has meters tightly placed in an 3D, XYZ-pattern and is set to display absolute magnitude of all components, hence it does not have to be placed in any certain position. It is this value that is used when measuring and calibrating an UFA according to standard. The probe is used throughout all radiated immunity tests and Ericsson considers its performance and accuracy sufficient.

Finding Temporary Cabling:
Since this test equipment has not been configured in this way before, there is no specific cabling for RF. To begin experimental testing, temporary cabling have to be sourced. There was an assortment of available cables belonging to the black box lab in storage. These were examined and the cables that fit for this purpose was chosen. The specifications for all cables that was available to choose from are shown in appendix 12. Two of cable 5 was chosen to connect the two RF out ports to the chamber wall connector, 50 cm long. These two cables did not handle CW 400 W but 350 W, so they are suited to handle shorter peaks up to 400 W, just as in this setup. The length of the cables was not optimal, but appropriate and their attenuation was relatively low. To connect the antenna to the wall mounted connector inside the chamber, the previously used UFB239C on EMC Rack 2 was used. The length was 180 cm and thus appropriate to experiment with antenna position. However because of this length, shorter cabling have to be ordered to the setup when the antenna is placed in its optimal position.

3.3 Software setup for testing

The software program that controls all equipment is EMC32. It is developed by Rohde & Schwarz and has good compatibility with all equipment used, especially from Rohde & Schwarz. All necessary actions can be performed in this software, testing every individual piece of equipment, creating tests and calibrations etc. Creating a test for a single point is done by defining the equipment used, E-field levels to generate and what data to generate in the test report. This process is clearly described in appendix 2. During a test to measure achievable E-field at any point where the E-field probe is placed, the levelling mode in the test setup is set to probe. This creates a feedback system from measured E-field to forward power, the power will be increased until the probe level specified in the test setup is achieved. Calibrating an UFA is setup similarly and clearly described in appendix 3. This will run a test with levelling mode set to probe like described earlier and record the output power levels as every point of the UFA is measured. The calibration created will be saved as a table with the highest required forward power for every point to reach the specified test level for all frequencies. To conduct a test on a product, the levelling mode is set to calibration. This will guarantee that every measuring point of the UFA will reach the specified field level. Checking if the UFA fulfils the uniformity demand is done by recording E-field level at every point when running leveling mode calibration and comparing it in e.g. Excel.

There are multiple parameters to monitor during a test, these are described in detail in appendix 2. The three most important parameters to analyse after a test is the measured E-field magnitude, recorded output power and recorded amplifier saturation. The E-field magnitude will tell if the equipment is insufficient to produce the specified field level in the test. By analysing in what regions the field level is not enough, information is obtained about which part of the setup that is insufficient and be analysed further. The power level will stay at maximum if the equipment is insufficient. If the field levels are obtained with an even power level curve that does not lay near the amplifier maximum output power level, then the equipment can be considered sufficient. If the power level curve is not even and displays spikes, it is a sign that reflections occur in the chamber. If these spikes reach maximum of the amplifier power output, then measures have to be taken to reduce reflections in the chamber. The amplifier saturation is very important to monitor, how it is measured is described in appendix 2. The effect of running an amplifier that is saturated is that the modulated test level will not reach the specified peak voltage and it will be distorted. Distortion includes harmonics that will be measured together with the fundamental modulation frequency by the E-field probe and display a larger field magnitude than the actual amplitude of the modulated test signal. This will under test the EUT.

3.4 Accuracy of measurements

The accuracy of this test equipment setup is the same as it was before the thesis since no part of the measuring equipment has been changed. Ericsson calibrates their measuring equipment each year as accredited labs also do, hence it is considered sufficient by Ericsson and will not be investigated further. The uncertainty in measurement that is introduced from human error is shown and further commented on in the results section as the same test setup was built up two subsequent times and displayed different results. This human error arises when placing the physical objects in the chamber in a position that differs a small amount in placement from the calibration setup. A minor angular displacement of antenna or longitudal displacement of measurement probe is difficult to avoid and will introduce the error levels obtained in the results section.

4 Results and Discussion

This section contains the results of the experimental process as well as a discussion, presented to answer each of the four research questions.

4.1 RQ1 - What practical measures has to be taken to install EMC Rack 2 in its new position?

This part summarises and presents all the practical solutions to install EMC Rack 2 in its new position. The practical measures solved were:

Table 3: Practical measures to accommodate for new position of EMC Rack 2

	New position
	Rack legs
	Antenna mount
	Power
	Data Connection
	Interlock Safety connections
	RF-connections to chamber
	Cabling

New position

The EMC Rack 2 that has previously been mobile and moved in and out of the chamber is instead to be seated just outside the EMC chamber door, as demonstrated in Figure 42.

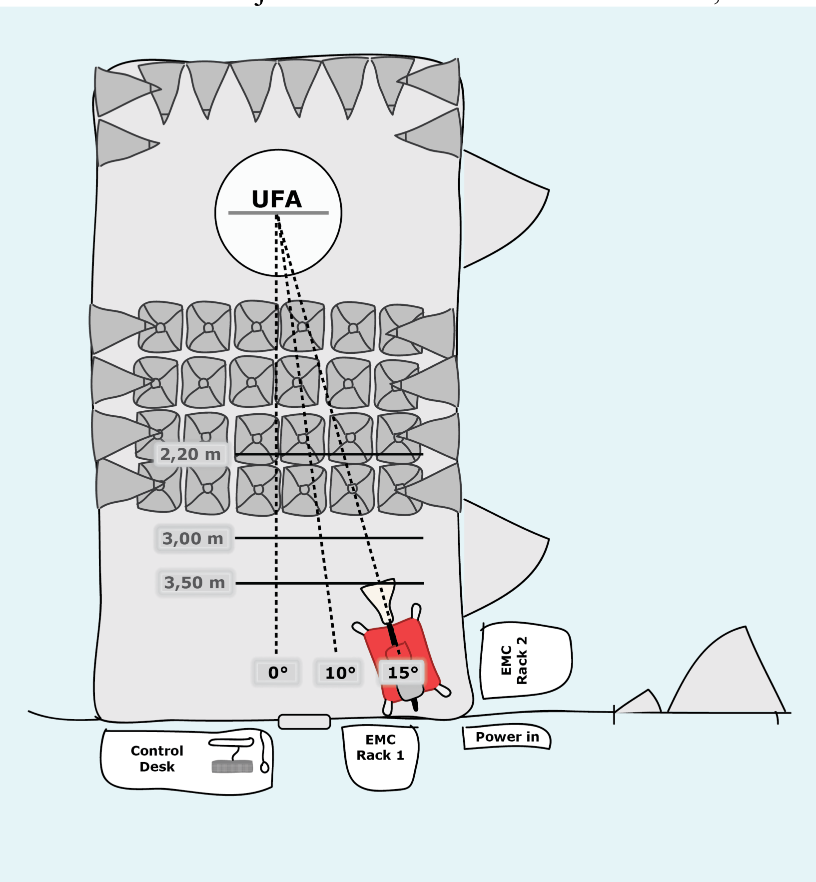


Figure 42: Overview illustration of chamber and control room

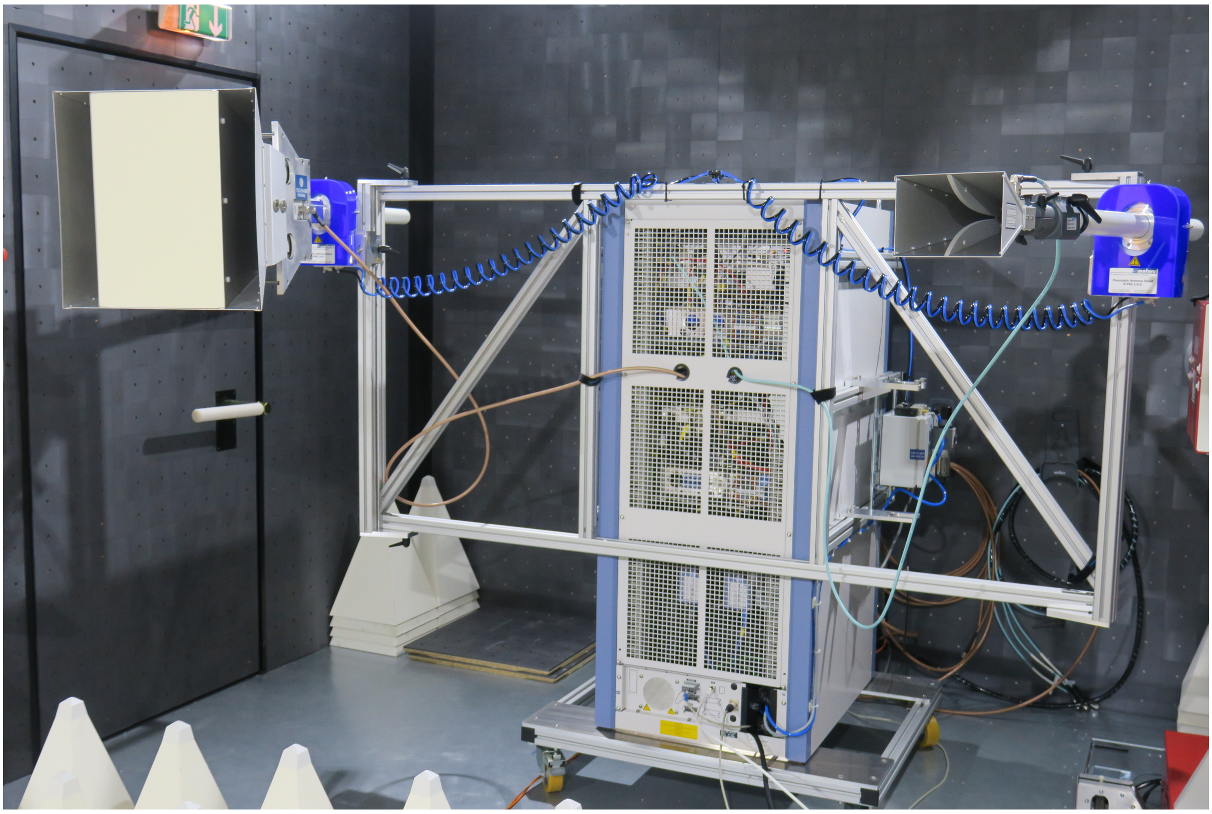


Figure 43: Emc Rack 2 in old, mobile configuration, pre-thesis - Picture from Jan Knipström

There are numerous changes required to allow for the EMC Rack 2 to be permanently installed at its new position. These are, Rack legs, Antenna mounts, Power, Data connection, Interlock safety connection, RF connectors to chamber and ordering proper cabling. All of the above was changed as following;

Rack Legs

In Figure 43 the original ”platform” on wheels that the rack is bolted on is shown. The new spot for the rack is a tight fit and requires a change to a smaller platform. Jan Knipström had ordered new wheels for the rack prior to the start of this thesis that arrived a few weeks after the start. Two people from Ericsson's technical department brought the rack to their workshop where they had the necessary equipment to lift the rack in its four lifting loops on top. The platform underneath was dismantled and four separate wheels was mounted.

Antenna Mounts

As seen in Figure 43 the antennas were mounted on white plastic pipes that were maneuvered by a compressor inside the rack to change polarisation. These plastic tubes have a diameter of 50 mm that the grey antenna mounts slides over and clamps on to. The smaller antenna BBHA9120B display the grey antenna mount very well in Figure 43. However, the new pipe on the red Frankonia antenna tower is a composite laminated pipe with diameter of 2 inches that equals 50,8 mm. Since the antennas shall be used with this tower from now on, the grey antenna mount of BBHA9120B needs to be machined to fit this pipe. This was not a problem with the antenna mount for BBHA9120J.

This problem was solved by a visit to the staff-workshop and help from authorized personnel Mart Sakalov. The mount was fastened in the lathe as seen in Figure 44 with a specially machined round bar that had the same dimension as the antenna attachment. The diameter was increased from 50 mm to 51 mm and the problem was solved.

Figure 44: Machining of Antenna Mount inside diameter – Picture, Oliver Djurle

Power

The rack requires a three-phase power connection from the electrical cabinet at the other side of the wall. To solve this problem the Ericsson internal electrical firm had to install a new fuse in the cabinet and route a three-phase cable through the wall and mount a female socket on the wall above the rack.

Data Connection

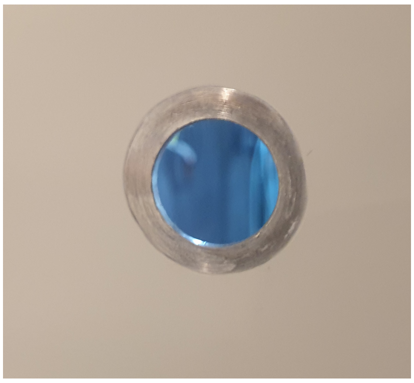
The control computer is located on the other side of the wall as drawn in Figure 42. As mentioned earlier, all of the EMC equipment is controlled with Ethernet-cables. From the computer there is an Ethernet connection to a switch in EMC rack 1 which needs to extend with a cable to EMC rack 2. This Ethernet cable has to be routed through the wall from EMC rack 1 to EMC rack 2. However, the different rooms that the chamber and the control computer sit in are separate fire zones in the building. This causes demands that any hole/feed through needs to be fireproofed when installed or opened. If any changes are to be made to further install cables/replace any damaged cable in the feedthrough, it has to be disassembled and fireproofed again. To avoid these problems, the Ericsson internal electrical firm was ordered to install a dual, female-to-female Ethernet connection-box on either side of the wall. This solution is modular, provides extra safety in case of breakage and supports additional installs.

Interlock Safety Connection
The interlock system is a 24 V- short circuit, security system that has to be tripped before any amplifier will engage RF. This is to make sure that both chamber doors are closed and flashing warning lights go off before RF is engaged, to ensure no one would open or enter the chamber during a test.
This system uses simple two wire unshielded cable with end mounted XLR microphone connectors.
As the solution for the Ethernet connection, the Ericsson internal electrical firm installed a female-to-female connection on either side of the wall to allow for this signal path, as well as supplying two male-to-male cables for connecting the EMC Rack 2.

RF-Connections to Chamber
Since the EMC rack 2 was located inside the chamber before, there were no RF connectors going out of the chamber except to EMC rack 1 which is located in the other room. Therefore, two RF connectors had to be mounted through the wall of the chamber behind EMC rack 2, with respect to shortest possible signal path. This install requires installing female-to-female N-connectors through the metal walls, as well as removing part of the ferrite tile inner walls. The entrepreneur Ronald Brander who retails Frankonia EMC chambers in Sweden carried out the installation.

Prior to this thesis, a large tile with 6 x 6 pcs of ferrites was removed and sent to Ronald, who removed 2 pcs of ferrites from it and removed the equivalent shape out of the compressed glued wood backing plate, the result is shown in
Figure 45.

Figure 45: Two pieces of ferrite removed from F006 tile



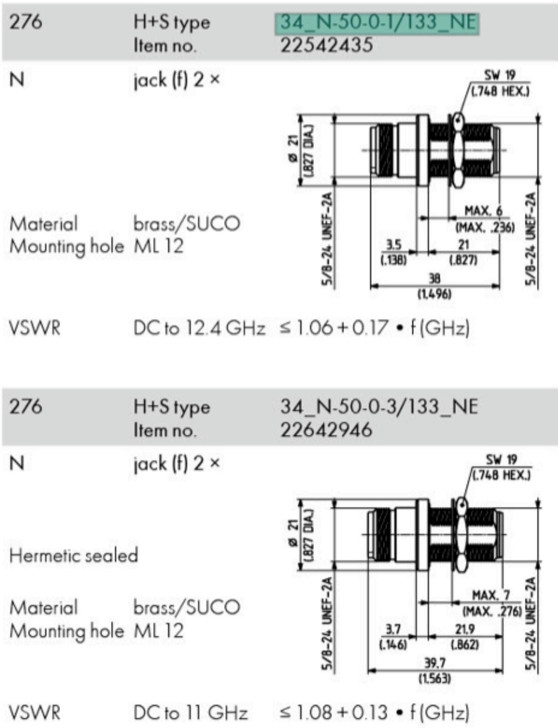
A couple of weeks into the thesis, Ronald returned with the plate and the tools to complete the install. The metal walls of the chamber are galvanized and powder coated, hence the paint needs to be stripped off to ensure proper earthing and EMC shielding around the connectors. This was done with a small piece of sanding paper on a bolt, which fit the pre-drilled holes for the connectors shown in Figure 46.

Figure 46: Through wall hole, sanded and ready for connector install

Two unknown female-to-female N-connectors were installed with a self-made stainless mesh washer to ensure full contact with the earthed metal wall. All practises according to Frankonia EMC guidelines of the chamber installation. Figure 47 shows the result.

With the stainless protective caps that thread on the connectors screwed on, all E-field on the outside of the chamber will stay out and all E-field within the chamber will stay on the inside of the wall. Best possible practise according to Uppsala University EMC course (Thottappillil, 2007).

Figure 47: One of two installed connectors



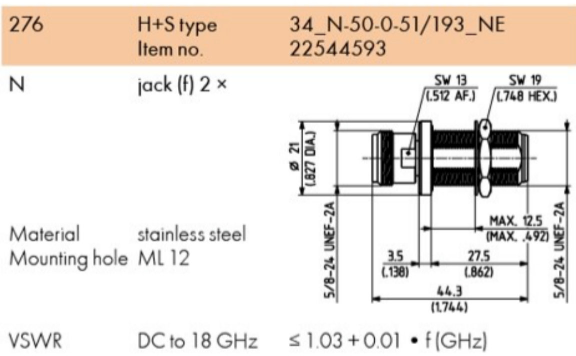
The N-connectors supplied by Ronald Brander was spare parts he had laying around, the make and model of them was never specified to us at Ericsson.

The connectors only stated “Suhner” which is part of the brand name “Huber & Suhner”. Researching H & S parts catalogue (Huber & Suhner, 2020) to find what type of connectors used resulted in two possible models shown in Figure 48, judging by measurements.

These two connectors show a significant VSWR of >2 at frequencies close to 10 GHz. A VSWR of 2 will reflect ≈12% of the power. (Walraven, 2006)

H&S offers a third N female to N female connector, which has significantly better properties. The specification is shown in Figure 49.

Figure 48: Unknown N-connectors, the two possible models - (Huber & Suhner, 2020)



Since the two connectors supplied had a significantly lower performance than the type shown in Figure 49. Two of those connectors were ordered and installed. The high performance connector is shown in Figure 50 below with already installed stainless washer and ready for install.

Figure 49: Best N-connector from Huber & Suhner - (Huber & Suhner, 2020)

After the connectors were installed, the noise floor in the chamber was recorded and compared to the reference noise floor. This procedure checks if excess noise enters the chamber after the changes has been made. The measured noise floor after the install did not deviate from the reference noise floor previous to the installation, hence the installation was considered successful.

Figure 50: High performance connector prepared for install

Cabling

Final Order

Consultation regarding cable choices from the cable supplier was received from Lars Wehlén. The decision was made to follow Lars recommendations and order UFB293C cable for all applications in lengths 2x 50 cm, 1x 120 cm, 1x, 220 cm. Two short ones for connecting rack to chamber, one short for back position of antenna tower inside the chamber and one longer cable for testing different positions of antenna in the chamber. The optimal cabling is shown in Figure 51 when it had just arrived.

Figure 51: Optimal cabling UFB293C

4.2 RQ2 - Where is the most optimal position of the antenna in the chamber?

Optimal antenna position

The best position for the antenna was to place it according to **Fel! Hittar inte referenskälla.**. The results from each experimental measurement is presented below.

Table 4: Variables of equipment placement within chamber

Placement of antenna (distance to UFA)	3,50 m
Utilisation of extra dampening cones	-
Angular displacement	15 degrees
UFA position	At turning table
Antenna height	1,0 m

The best positioning of the antenna to cover the UFA within the gain lobe of the antennas was to place it at the largest distance from UFA allowed by the physical dimensions of the chamber. The best performing offset angle was 15 degrees since it reduced peaks in forward power obtained from reflections.

Obtaining an UFA of 1,0 x 1,0 m at the turning table was not achievable as presented in appendix 5. The largest UFA possible at the turning table is 0,61 x 0,61 m according to theory, and the size 0,5 x 0,5 m was experimentally verified in Figure 52 and Figure 53.

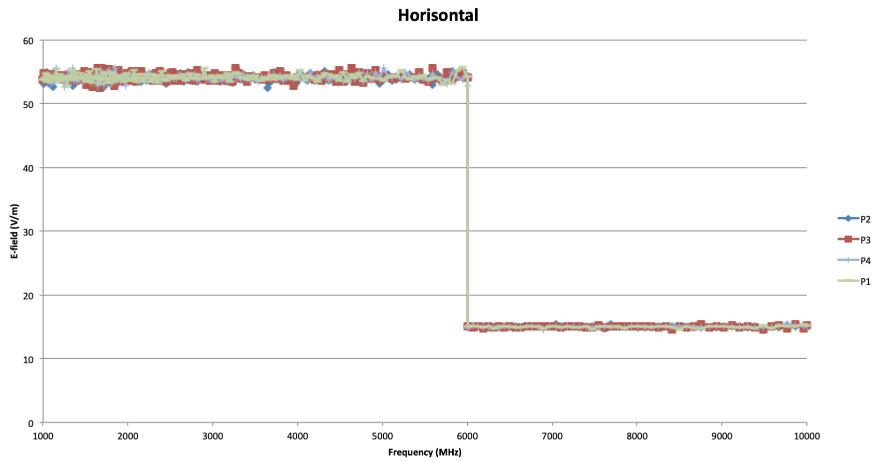


Figure 52: Measured E-field of UFA at turning table, 3,50 m, 15-degrees 0,5 x 0,5 m, horizontal polarisation

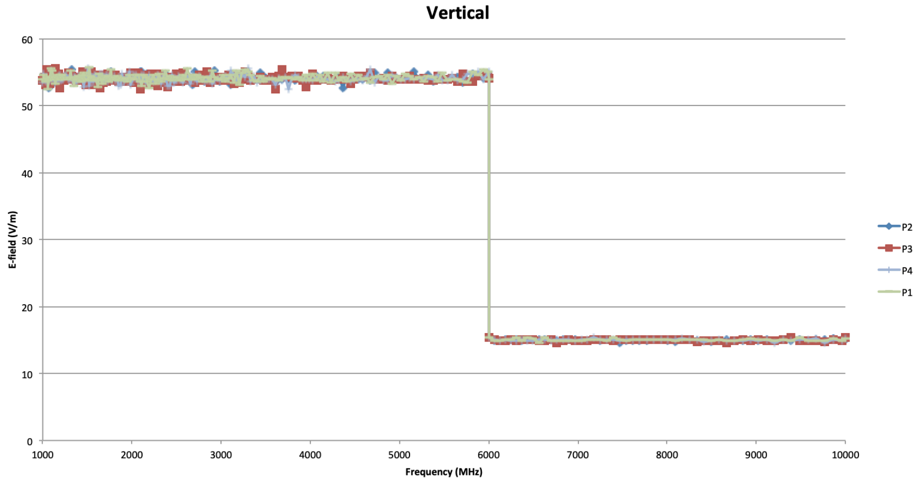


Figure 53: Measured E-field of UFA at turning table, 3,50 m, 15 degrees 0,5 x 0,5 m, vertical polarisation

In Figure 52 and Figure 53 all points measured up to the internal test levels with not a single point lacking in field strength.

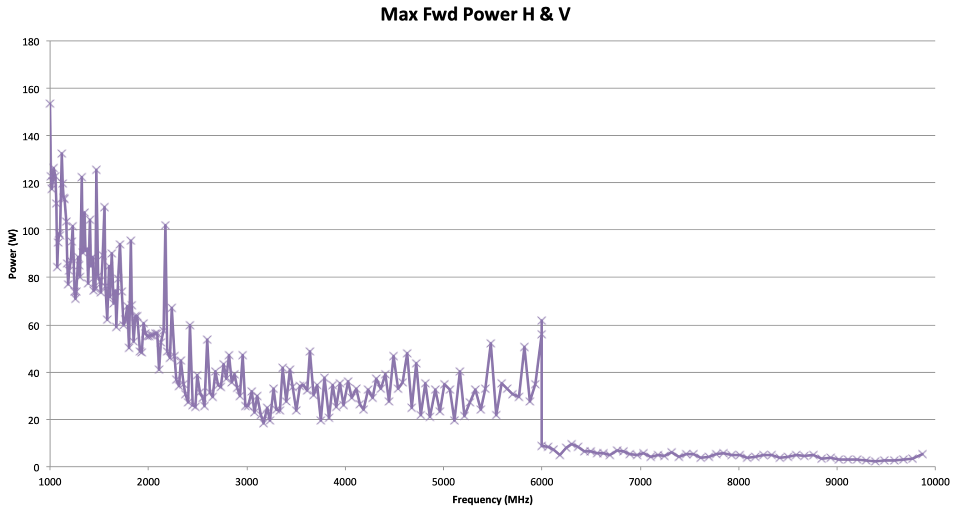


Figure 54: Measured Fwd power for 0,5 x 0,5 m 3,50 m 15-degrees offset UFA

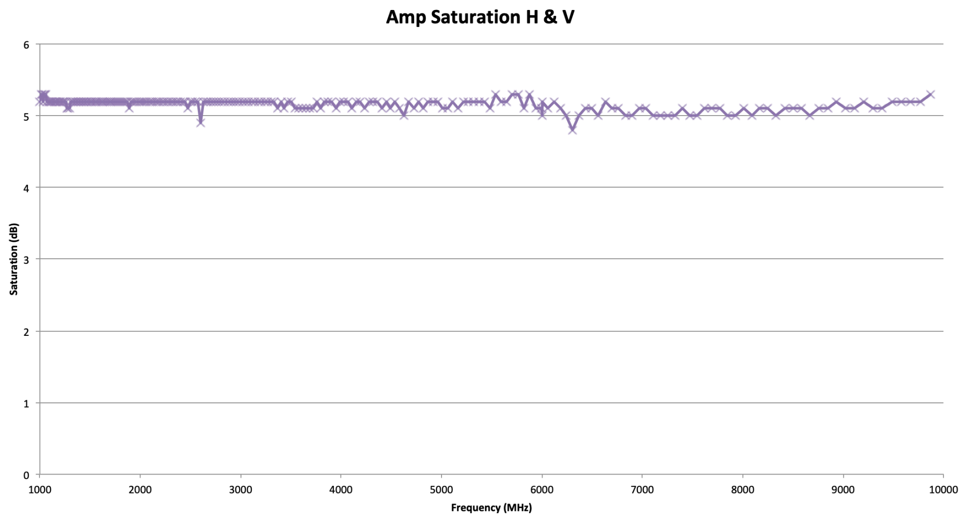


Figure 55: Measured Amplifier saturation for 0,5 x 0,5 m 3,50 m 15-degrees offset UFA

The forward power levels from the amplifiers shown in Figure 54 generally never reaches more than 40% or less of their max capacity within the entire interval (<60% for peaks). This is also shown when analysing the amplifier saturation curve in Figure 55. It keeps its level at 5 dB and show no sign of saturation.

When this smaller UFA of 0,5 x 0,5 m was accomplished with low forward power levels for the 1-6 GHz setup, the smaller BBHA9120B antenna was mounted to the antenna tower without any change of the towers placement. This results in that the tip of the smaller antenna is located at a distance of 3,825 m from the UFA and not 3,50 m. This measure did not change the result noteworthy and saves time when operating the setup change for a full test.

Verifying with theory using equation (7) and with an opening angle of 14-degree and a distance of 3,5 m from antenna to UFA, the largest UFA possible to fit on the turning table is 0,61 x 0,61 m.

Placement of antenna (distance to UFA)

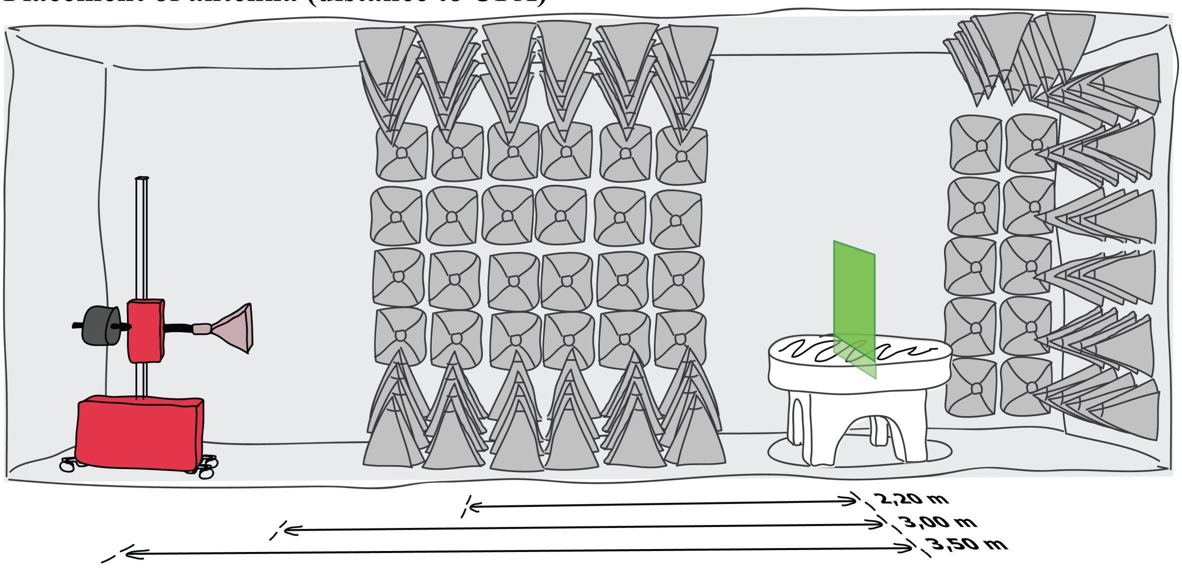


Figure 56: Illustration of test setup for variable - placement of antenna, distance to UFA

The experimental values for this measurement are shown in appendix 5
The distance from the UFA to antenna was tested at three distances:
The closest extreme was 2,20 m without moving the stationary cones and ferrite tiles in the middle of the room, on the floor. The results from this measurement show lack of E-field in all points except the middle horizontal row. The amplifiers reached maximum forward power, which means that these points are not covered by the antenna beamwidth.

The middle point was at 3,00 m and gave better results. The measured field levels showed that a greater part of the UFA was covered by the antenna beamwidth. The points from 2,20 m that was lacking in E-field strength showed less lack in field strength for 3,00 m. The dips in E-field were not as deep as 2,20 m and affected fewer points.

At the furthest extreme with a distance of 3,50 m between antenna and UFA, the antenna almost touched the chamber wall. It gave the best results, as a large part as possible of the UFA was covered by the antenna gain lobe, since the outermost points showed significantly less dips in E-field.

In conclusion, the best position of antenna (distance to UFA) was as far away as possible in the chamber, this allowed the UFA to fit within the antenna gain lobe to a larger extent. However, the increased distance between antenna and UFA increased the level of required forward power as theory states. This result was obtained by increasing the distance between antenna and UFA to 3,50 m.

In conclusion, the antenna tower can not be moved any further back to enclose the entire 1,0 x 1,0 m UFA. The chamber is too short/the beamwidth of the antenna BBHA9120J is too narrow. This supports the statement in theory where it is concluded that the distance between the antenna and UFA needs to exceed 5,76 m to fully enclose it for BBHA9120J. The UFA of 1,0 x 1,0 m is not achieavable in the chamber.

Utilisation of extra dampening cones

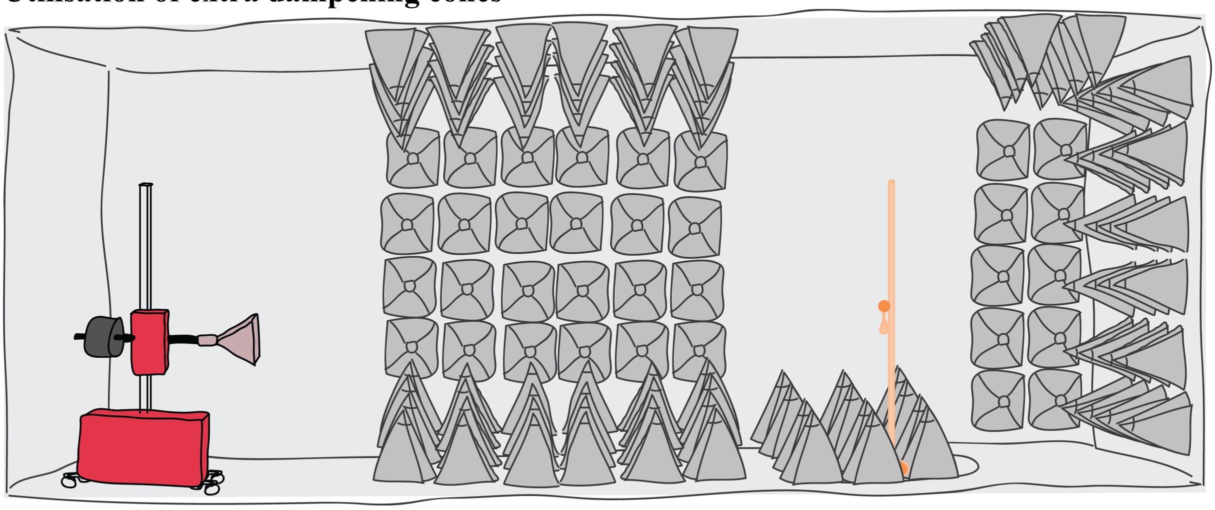


Figure 57: Illustration of measuring setup for variable - cones

The experimental values for this measurement are shown in appendix 6.
Cones were inserted in the chamber and placed on the floor both underneath the UFA and further back against the rear wall. This measure was to decrease reflections in the UFA. The results were varied, less reflections were obtained when cones were placed under the UFA however some reflections got worse. In conclusion, placing the cones at the back of the chamber showed no distinct difference for better or worse. Hence no utilisation of cones was relevant.

Angular displacement

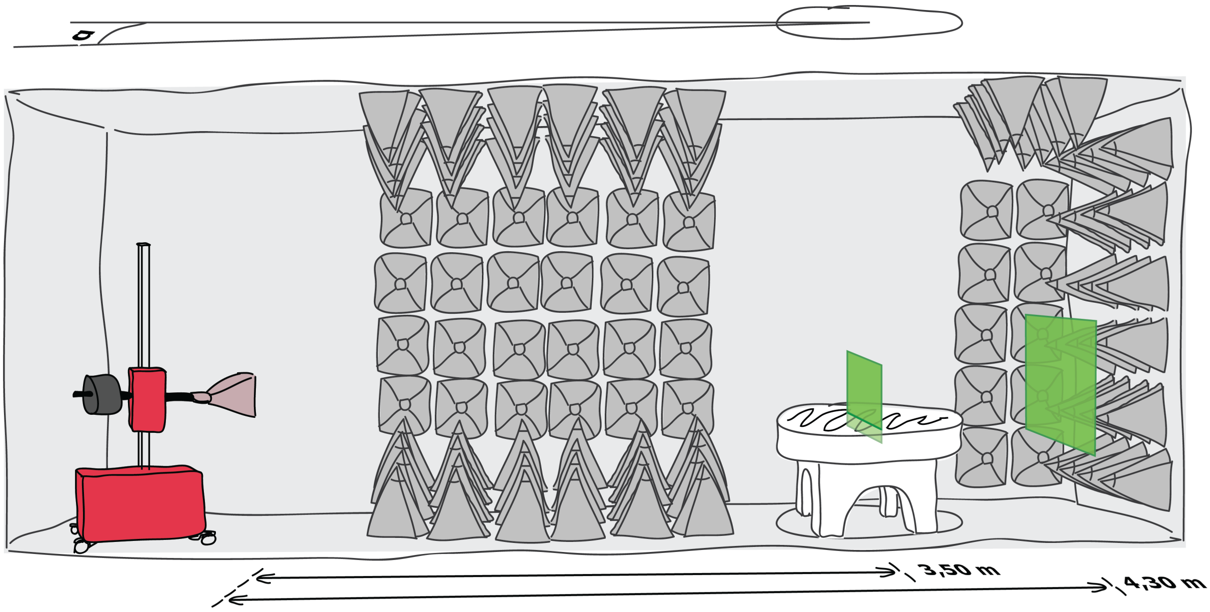


Figure 58: Experimental setup for measuring variable - angular displacement

The experimental values for this measurement are shown in appendix 7.
The experiments to find how the angle of attack will effect reflections in the chamber included measuring 10 & 15 degree "Alfa" in the top of Figure 58 above and comparing to the case with 0-degree offset. The previously found, best distance between antenna and UFA of 3,50 m was chosen for both angles.

The introduction of a 10-degree offset angle over 0-degree did not affect the overall power level of the test. However, peak powers that arise due to reflections in the chamber was decreased by an average of 50 W. This phenomenon is explained in the theory section, that introducing an angle will decrease symmetrical sidewall reflections and rear wall reflections that no longer are perpendicularly reflected straight back.

Increasing the offset angle to 15 degrees continued the same trend, keeping the general power level the same as before and decreasing peak forward power due to further decreasing symmetrical sidewall and rear wall reflections. It was therefore concluded that the maximum achievable 15-degree angle was the optimal angle.

In conclusion, it is not possible to achieve an UFA of 1,0 x 1,0 m on the turning table even when including up to 15 degrees offset angle. To see if it is possible to obtain an 1,0 x 1,0 m UFA anywhere in the chamber, the UFA itself was moved from the turning table, further back against the rear wall to increase its covered area within the antenna gain lobes, as seen under the next title.

UFA position
The experimental values for this measurement are shown in appendix 8.
Two distances were tested. Moving the UFA closer to the antenna, from the back wall <3,0 m and moving it closer to the back wall >3,0 m. As stated in the theory section, reflections between antenna and UFA are expected to decrease when moving the UFA closer to the antenna, thus increasing the exit angle of wall reflections and their negative dB compared to the center axis of gain lobe. However, if the UFA does not fit within the beamwidth of the

horn antenna, which it does not according to earlier results, this procedure will only show worse results for the case of moving it closer to the antenna.

Moving the UFA closer to the antenna resulted in worse results since it clearly does not fit within the gain lobe of the antenna. Moving it further from the antenna at a maximum achievable distance of 4,3 m apart showed better results. This result was in accordance with the results from the first experiments to move the antenna (distance to UFA).

The result of 4,3 m apart was also tested with the 15-degree angular offset to examine the possibility of a 1,0 x 1,0 m UFA with the optimal placement of antenna and maximum distance between antenna and UFA. The results from this measurement are shown in appendix 9. The larger UFA is still outside of the beamwidth of the antennas, however the results only show lack in field strength at two points that can be neglected due to the UFA demands in EN61000-4-3. Even though this UFA would almost pass the uniformity demands, it is not considered an option to use since it is not placed on the turning table.

Antenna height

The antenna height was neglected to test since no earlier results showed different outcomes for points that were on the top or bottom with the antenna at the height of the UFA center.

4.3 RQ3 - Does the reference calibration fulfil the demands from standards and correspond to the theoretical performance of EMC Rack 2?

Reference calibration according to test standards

The following describes the results of performing a reference calibration on the 0,5 x 0,5 m UFA at 3,50 m distance with 15 degrees offset angle.

The setup as 3,5 m, 15-degree 0,5 x 0,5 m UFA on the turning table was built up and reference calibrated using the procedure described in appendix 3. After the calibration file was obtained, the measuring points were measured by running the calibration level. 8 times for both polarisations, all four measuring points over the frequency span 1 – 6 GHz, and then repeated 8 more times in the 6 - 10 GHz frequency span. The results from these 16 tests are presented in Figure 59 and Figure 60 below.

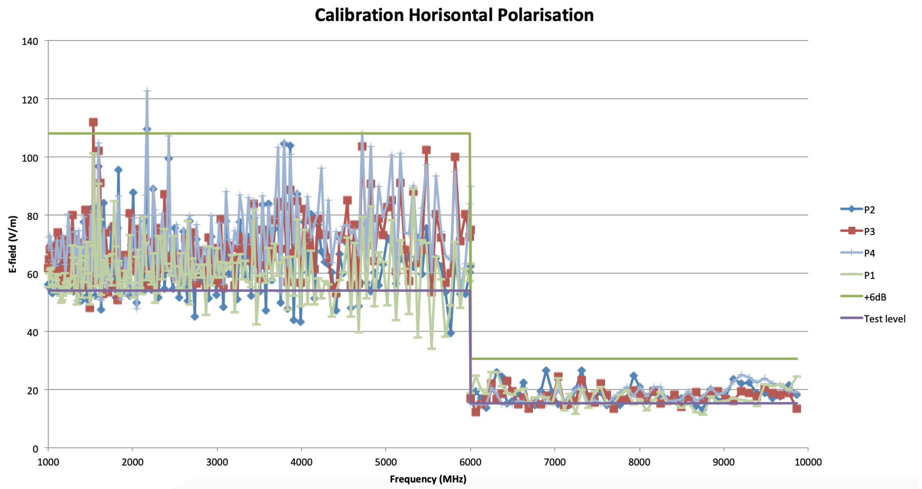


Figure 59: Measured E-field of 0,5 x 0,5 m UFA at turning table, 3,50 m, 15-degrees, horizontal polarisation calibrated with new cabling

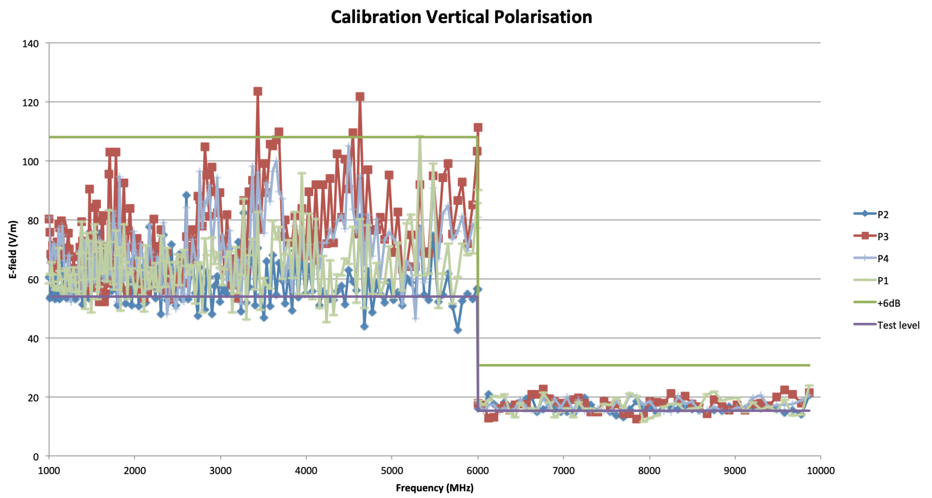


Figure 60: Measured E-field of 0,5 x 0,5 m UFA at turning table, 3,50 m, 15-degrees, vertical polarisation calibrated with new cabling

The results show some unexpected behaviour that occured where the points dip down under the set test level and over the +6 dB uniformity limit. This phenomenon of measuring lower values than the calibration can only arise because of measuring uncertainty. All the measuring points reached the set test level in the recorded calibration. Examples of measuring uncertainties causing this are antenna angle, not exactly the same test position of E-field probe placement on the UFA etc. In fact, this deviation from the set test level is what defines the Radiated immunity measurement uncertainty at Ericsson. Since the test was set up in the same configuration two times, the variation between the two is the uncertainty of measurement, or in other words, error margin. The largest error in Figure 60 is ≈10 V/m.

8 frequencies out of all 1864 measured were above the +6 dB limit. This is 0,4 % that deviates above the uniformity demand, which is considered to be fully OK by Ericsson since any ”over testing” of the products is not harmful to the end result products, only the opposite. If this were the case for an accredited testing house, the UFA would not be valid because of these 8 points.

Experimental versus theoretical performance

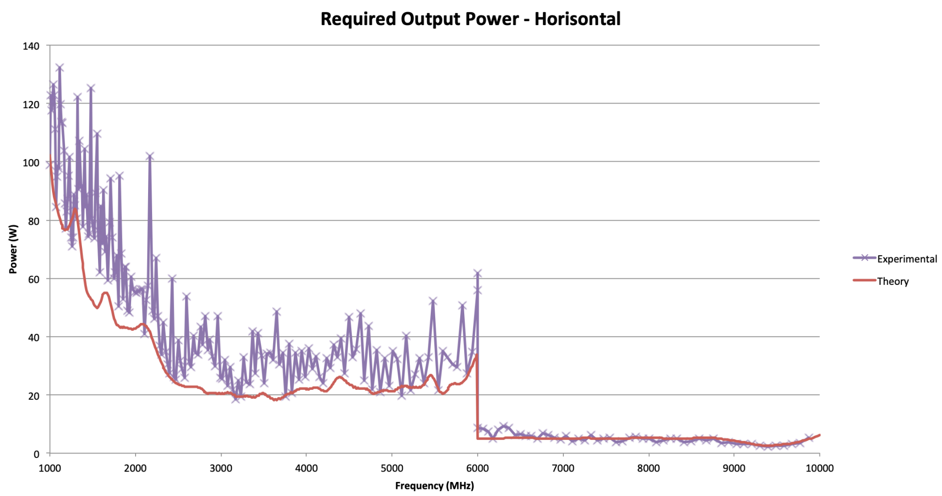


Figure 61: Comparison of output power in theory and experiment, horizontal

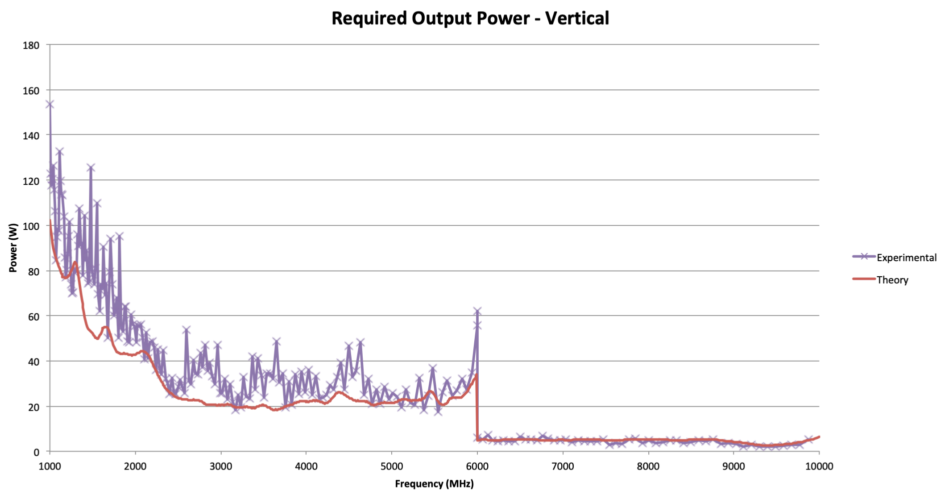


Figure 62: Comparison of output power in theory and experiment, vertical

In Figure 61 and Figure 62 above, the theoretical forward power for this calibration is compared to the experimentally recorded forward power. This small size UFA that is completely covered in the beamwidth of the antennas does not require the power levels of an UFA that is as large as the beamwidth. Notice that the theoretical power level is just below the experimental values. The effects seen above must arise because of parameters that was neglected in the theory chapter. Parameters as the reflections in the chamber. This effect is not seen to this extent in the higher frequency span of 6-10 GHz where they overlap very well. Overall, the difference between theoretic calculation and experimental results is small and the results can be considered very satisfactory in the field of EMC where there are many phenomena that can occur and cause diversions from theory.

Comparing of the power level for the 0,5 x 0,5 m UFA prior to the thesis compared to the recorded power level of the achieved 0,5 x 0,5 m UFA post thesis gives some conclusions that can be established. The general power level prior to the thesis was lower, which is explained in theory because the antenna before the thesis was positioned closer to the UFA. The higher power level after the thesis is still low compared to the amplifier power potential and will thus not cause the amplifiers to run hot during prolonged use. It will also illuminate the UFA with a more homogenous field because of the increased distance in-between the antenna and UFA, This will result in more accurate level readings when placing the probe next to the EUT to validate test levels when running a test. The new, optimal placement of antenna produces a larger UFA that is more homogenous at the turning table. Because of this, any error in angular displacement of the antenna will not be as critical due to the larger gain lobe covering the UFA.

4.4 RQ4 - What will be the operation procedure of this setup?

To finish off this thesis for Ericsson, a test instruction was written which presents the practical setup of the radiated immunity 1 - 10 GHz setup. Main points of focus to create a comprehensive instruction were to include pictures of the setup and screenshots of the settings in EMC32. Also, giving short motivations of why things are done a certain way to increase understanding for the setup operator. The test instruction is placed in appendix 1.

4.5 General discussion

Measuring procedure

None of the measurements showed any significant surprising behaviour, however the result from addition of cones in the chamber was proven less efficient than expected. These expectations had no calculated theoretical background, only conceptual.

Limitations

The measurements took long time to perform. A 9-point measurement of UFA required up to 7 hours to measure and enter all measurement data in Excel to analyse. This was the time required only for a 1-6 GHz test. The measurements for 6-10 GHz took a lot less time since they included significantly fewer data points because of the logarithmic steps. This long measuring time, in combination with waiting for available timeslots to book the chamber, long delivery time of the new cabling and the impact of COVID-19 put stress on the timeline of this thesis.

The software EMC32 is under-developed and includes lots of bugs and errors. A few of these issues that arose during the measuring process was:

- It gave self induced commands to the antenna tower to change height. This is problematic if the antenna cabling is short, a sudden movement of the antenna can tear apart expensive cabling with long delivery times. Luckily, when this occurred there was no cabling attached.
- It could stop mid-test as the signal generator forward level registered at the amplifier was too low and drowned by the noise level. This was another self induced problem since it was the program itself that set the signal generator level that was drowned as a start value. The result was that the test had to be re-initiated to finish.

5 Conclusions

This closing chapter sums up the main findings and contributions of the thesis, considers potential limitations and further outlines opportunities for future research.

This thesis has met its purpose by performing the objectives and answering the research questions stated. It has covered practical work to reinstall the EMC Rack 2 at a new position as well as optimising the placement of antennas inside the chamber and writing the test standard operating procedure. Consequently, Ericsson has the opportunity to execute radiated immunity 1 - 10 GHz tests with a calibrated UFA with the size of 0,5 x 0,5 m at the turning table and the EMC Rack 2 outside of the chamber. This allows Ericsson to perform all EMC-tests in-house for product verification during the entire design process of their 5G-baseband products. It has also provided the results that a 1,0 x 1,0 m UFA is not achievable at the turning table, which was Ericsson's initial statement when ordering the test equipment.

5.1 Test equipment setup

The optimal placement of antenna was found by theoretically analysing the test equipment followed by experimental verification. The optimal placement was obtained by increasing the distance as much as possible between antenna and UFA to enclose the UFA within the antenna gain lobe. An offset angle was introduced to minimise symmetrical wall and rear wall reflections in the chamber, the maximum angle of 15 degrees gave the best results. The results of horizontal polarisation compared to vertical polarisation did not show any significant difference.

The limit of the test equipment is the antenna BBHA9120J for 1-6 GHz that has a too narrow beamwidth and can theoretically only cover an UFA of 0,61 x 0,61 m at the turning table.

5.2 Future outlooks

The theory stated that the chamber was small/the antennas were too narrow in beamwidth. This was the issue that caused lack in performances when the rack was installed in 2017.

To address this issue, a new investment in a replacement antenna for BBHA9120J can allow for a larger UFA, which is needed to comfortably test equipment that is larger or that has long cabling that has to be looped inside the UFA when tested. Higher gain antennas come with lower beamwidth opening angles, that is their trade-off. The current test equipment uses up to 40% of its amplifier power potential (<60% for peaks) for 1-6 GHz 3,50 m away from the UFA, an increase in used output power is possible.

Option 1: This trade-off would result in searching for an antenna with beamwidth opening angle of at least 12 degrees, which would allow for a 1,0 x 1,0 m at 3,50 m away from the UFA at the turning table and with as low drop in gain as possible. The placement of the antenna would be the same, at 3,50 m distance from UFA to allow for use of the same cabling from the wall connectors. The possibility of this solely depends on the antenna found and the output power available.

Option 2: Moving the antenna closer to the UFA and finding an antenna with broader beamwidth angle than 12 degrees and less gain. This is essentially the same procedure as option 1 except that the larger decrease in gain of the antenna has to correspond to the decrease in required power from moving it closer to the UFA.

This has to be studied in the same manner that this thesis examined the two already available antennas. With respect to all parameters to include near and far field, power handling, etc. Practical aspects such as adding a larger measurement error due to an angular displacement of the antenna at a further distance compared to a shorter distance should also be taken into account as well as the magnitude of wall/floor/ceiling reflections that increase when the antenna is placed further away from the EUT.

6 References

Achillie, D., 2017. *iz2uuf.net*. [Online] Available at: https://www.iz2uuf.net/wp/index.php/2017/07/29/the-myth-of-reflected-power/ [Accessed 05 May 2020].

AR RF/Microwave instrumentation, 2007. *AR RF/Microwave instrumentation products*. [Online] Available at: https://www.arworld.us/html/18200.asp?id=1094 [Accessed 05 May 2020].

Armstrong, K., 2007. *emc standards*. [Online] Available at: https://www.emcstandards.co.uk/files/61000-4-3_immunity_to_radiated_rfi.pdf [Accessed 05 May 2020].

ARRL - Amateur Radio Relay League, 2007. *ARRL Antenna Handbook*. 21st ed. ARRL. page 43 in PDF.

Balanis, C.A., 2016. *Antenna Theory - Analysis and Design*. 4th ed. Wiley.

Bevelacqua, P.J., 2009. *antenna theory*. [Online] Available at: http://www.antenna-theory.com/definitions/vswr-calculator.php [Accessed 05 May 2020].

Don W. Metzger, J.D.N.R.M.S., 1991. Near-Field Patterns from Pyramidal Horn Antennas: Numerical Calculation and Experimental Verification. *IEEE Transactions on electromagnetic compatibility*, Augustus.

Ericsson, 2018. *Ericsson.com*. [Online] Available at: https://www.ericsson.com/4add36/assets/local/mobility-report/documents/2018/emr-june-2018-securing-the-right-spectrum-for-5g.pdf [Accessed 05 May 2020]. Securing the right spectrum for 5G - extract from Ericsson mobility report.

Ericsson, 2020. *Ericsson.com*. [Online] Available at: https://www.ericsson.com/en/newsroom/photo-library/network-products [Accessed 05 May 2020].

ETSI, 2016. *ETSI.org*. [Online] Available at: https://www.etsi.org/deliver/etsi_en/301400_301499/30148901/02.01.01_60/en_30148901v020101p.pdf [Accessed 05 May 2020].

ETSI, 2019. *ETSI.org*. [Online] Available at: https://www.etsi.org/deliver/etsi_EN/301400_301499/30148950/02.01.01_30/en_30148950v020101v.pdf [Accessed 05 May 2020]. page 32.

Frankonia GmbH, 2013. *Frankonia GmbH*. [Online] [Accessed 05 May 2020].

Frankonia GmbH, 2013. *gtemcell*. [Online] Available at: http://www.gtemcell.com/wp-content/uploads/2013/01/GTEMCELL-Frankonia-FrankoSorb-F006-Ferrite-absorber.pdf [Accessed 05 May 2020]. Datasheet aquired from frankonia via E-mail. Also available via this website.

Huber & Suhner, 2020. *HUBER+SUHNER RF-Connectors catalog*. [Online] Available at: https://literature.hubersuhner.com/Technologies/Radiofrequency/RFConnectorsEN/?page=504 [Accessed 04 May 2020]. sid.504-505.

IEC, 2006. *Electromagnetic compatibility (EMC) - Part 4-3: Testing and measuring techniques - Radiated, radio-frequency, electromagnetic field immunity test*. Standard. IEC.

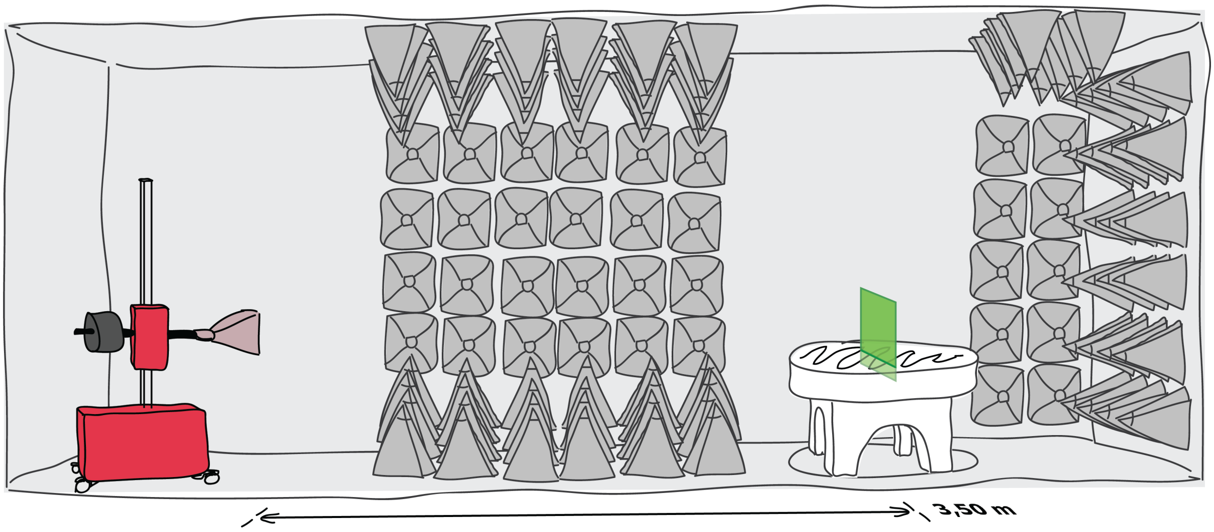
International Telecommunication Union - Radiocommunication Sector, 2012. *itu.int*. [Online] Available at: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.676-9-201202-S!PDF-E.pdf [Accessed 05 May 2020].

Isacsson, P., 2020. *Radiated Immunity, What is it and How Does it Work*. Presentation. Per Isacsson Consulting. Presentation created for educational start to this EMC thesis.
Kazuhiro Takaya, N.N.Y.H.Y.O., 2016. Study on Test Distance between EUT and Antenna for Radiated Immunity Test In Close Proximity to Equipment. In *International Symposium on Electromagnetic Compatibility - EMC Europe 2016*. Wroclaw, Poland, 2016. NTT Network Technology Laboratories.
Rohde & Schwarz, 2019. *Rohde & Schwarz*. [Online] Available at: https://www.rohde-schwarz.com/cz/brochure-datasheet/bba150/ [Accessed 05 May 2020]. p 58 & 70.
Rosenberger, 2014. *Rosenberger*. [Online] Available at: http://rosenberger.co.kr/data/TEST&MEASUREMENT%20adaptors.pdf [Accessed 05 May 2020].
Schwarzbeck Mess - Elektronik, n.d. *schwarzbeck mess - elektronik*. [Online] Available at: http://www.schwarzbeck.de/en/component/content/article/54-double-ridged-horn-antenna/379-bbha-9120-j-broadband-high-gain-horn-antenna.html [Accessed 05 May 2020].
Schwarzbeck Mess - Elektronik, n.d. *schwarzbeck mess elektronik*. [Online] Available at: http://www.schwarzbeck.de/en/component/content/article/54-double-ridged-horn-antenna/402-bbha-9120b-double-ridged-broadband-horn-antenna.html [Accessed 05 May 2020].
Sevgi, L., 2017. *A Practical Guide to EMC Engineering*. Norwood, Maine, USA: Artech House. sida 111.
Telcordia Technologies, 2011. *Electromagnetic Compatibility (EMC) and Electrical Safety - Generic Critera for Network Telecommunications Equipment*. Standard. Telcordia Technologies.
Thottappillil, R., 2007. Chapter 5 - Solution to EMC Problems. In Thottappillil, R. *Course Notes on Electromagnetic Compatibiliyt (EMC): Theory and Practice*. Uppsala, Sweden: Uppsala Universitet. p.99.
US Naval Air Warfare Center, 2013. *Electronic Warfare and Radar Systems - Engineering Handbook*. California, USA: United States Naval Air Warfare Center.
Wallander, P., 1998. *Den första boken om DIGITAL RADIO*. 1st ed. Älvsjö, Sverige: Per Wallander Antenn AB.
Walraven, D., 2006. Understanding SWR by Example - Take the Mystery and Mystique Out of Standing Wave Ratio. *QST*.
Wehlen, L., 2020. *Concultation Lars Wehlen, Rosenberger*. Kista, Sverige.
Y. Rahmat-Samii, L.I.W.a.R.G.Y., 1995. The UCLA Bi-polar Planar-Near-Field Antenna Measurement and Diagnostics Range. *IEEE Antennas & Propagation Magazine*.

7 Appendix

7.1 Appendix 1 - Operation procedure instruction

Daily Check Radiated Immunity 1 GHz - 6 GHz



UFA Size – 0,5 x 0,5 m centered on turning table, 4 point calibration
UFA bottom height – 0,8 m (at table top)
ANT tip to UFA – 3,50 m
ANT offset angle – 15 deg
ANT – BBHA9120J

1. Position of the Antenna

There are two markings in the floor to match the arrow on the front of the antenna tower as well as the middle of the antenna leading edge. Use a plummet in a string to match the antenna marking.

The arrow at the rear of the antenna tower is too far in the corner, which makes it impossible to see the placement of it.

Mount the antenna in the correct polarization. Wait with connecting any cabling. Use the little spirit level to make sure that it is level. If not sure, you can check the polarization in EMC32, by device list – antenna tower – properties. If it states " Hor-Ver" then it is currently in horizontal polarization and ready to change to vertical.

Please check that the antenna tower responds to given commands (height/polarization), since the cables to antenna are short, a malfunction and uncontrollable raise/lowering action can rip the cable in two. If not, enter device list and and activate the connection by pressing "physical" then back to "virtual".

2. **Connect Cables**

The following cabling needs to be connected.

- 3-Phase power to EMC rack 2
- Ethernet connection from EMC rack 1 through wall to EMC rack 2
- Interlock XLR cable from EMC rack 1 through wall to EMC rack 2
- Orange field probe

- RF out from EMC rack 2 to chamber wall connector CABLE X
- Chamber wall connector to antenna CABLE X

3. **Field probe**

Place the field probe FL7018, using the plastic holder, as indicated in the picture above.

Connect the fiberoptic cables to the field probe. Do not force a connection, it might harm the connectors.
Turn on the Laser Probe Interface in the control rack (EMC Rack 1) by first turning the key to "enable" and then press the button to "ON".

4. **Rack and Computer**

Power up the signal generator and amplifiers in EMC rack 2. All of the amplifiers are interconnected so powering up one will power up all.

Go in to the device list and make sure that the rest of the sensors are active. Double click on the following and check the box “Manual” then “Active”XXXXXXXXX. These are the only parameters that can possibly harm the system if not properly active.

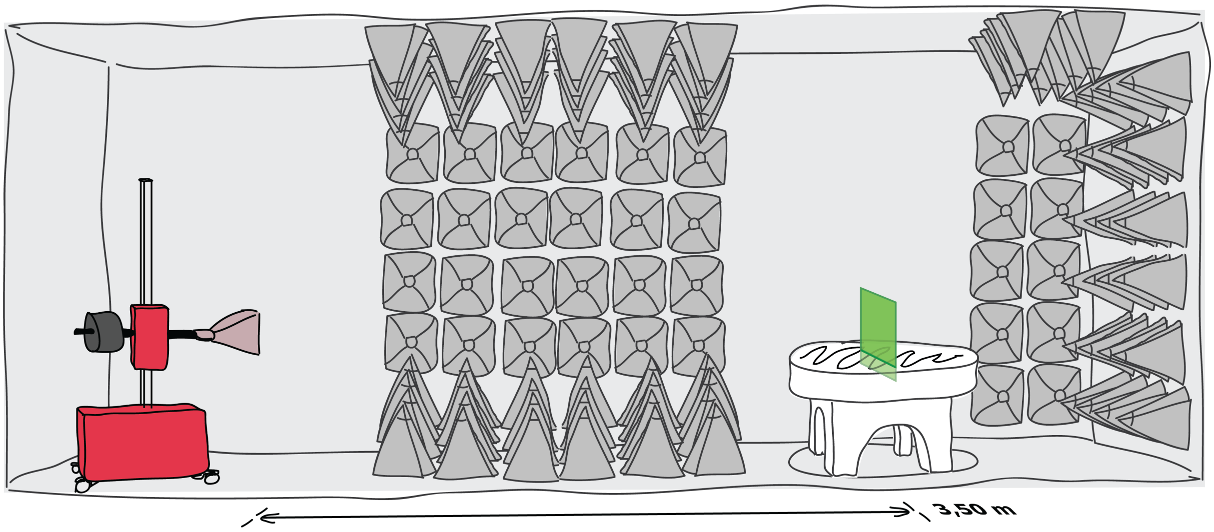
Fwd power meter
Rev power meter

Navigate to folder,”Daily_Check_Radiated_Immunity”. Its location is
EMS Scan\ XXX.

Start the test by right clicking the relevant script and choose **New Test**.

When the test is completed an information window will pop-up. The information is about what parameters to check in the daily test. Make sure that the parameters are within accepted tolerances. If not, redo the test.

Daily Check Radiated Immunity 6 GHz - 10 GHz



UFA Size – 0,5 x 0,5 m centered on turning table, 4 point calibration
UFA bottom height – 0,8 m (at table top)
ANT tip to UFA – 3,825 m
ANT offset angle – 15 deg
ANT – BBHA9120B

1. Position of the Antenna

There are two markings in the floor to match the arrow on the front of the antenna tower as well as the middle of the antenna leading edge. Use a plummet in a string to match the antenna marking.

The rear of the antenna tower is too far in the corner which makes it impossible to see the placement of the back arrow.

Mount the antenna in the correct polarization. Wait with installing the cabling. Use the little spirit level to make sure that it is level. If not sure, you can check the polarization in EMC32, by device list – antenna tower – properties. If it states " Hor-Ver" then it is currently in horizontal polarization and ready to change to vertical.

Please check that the antenna tower responds to given commands (height/polarization), since the cables to antenna are short, a malfunction and uncontrollable raise/lowering action can rip the cable in two. If not, enter device list and and activate the connection by pressing "physical" then back to "virtual".

2. Connect Cables

The following cabling needs to be connected.

- 3-Phase power to EMC rack 2
- Ethernet connection from EMC rack 1 through wall to EMC rack 2
- Interlock XLR cable from EMC rack 1 to wall to EMC rack 2
- Orange field probe

- RF out BONN amplifier, from EMC rack 2 to wall connector CABLE X
- Wall connector to antenna CABLE X
- Antenna

5. Field probe

Place the field probe FL7018, using the plastic holder, as indicated in the picture above.

Connect the fiberoptic cables to the field probe. Do not force a connection,it might harm the connectors.
Turn on the Laser Probe Interface in the control rack (EMC Rack 1) by forst turning the key to “enable” and then press the button to “ON”.

6. Rack and Computer

-Go in to the device list and make sure that all sensors are active. Double click on the following and check the box “Manual” then “Active”XXXXXXXXX. These are the only parameters that can possibly harm the system if not properly active.

Fwd power meter
Rev power meter
Antenna tower
Amplifier BONN

-The loan BONN amplifier is a solid-state amplifier with large bandwidth, hence it uses two bands for transmitting 1-6 GHz and 6-18 GHz. Referenced as “Band 1” & “Band 2”. By default it starts up in “Band 1” this can be changed in two ways. On the amplifier in the menu, accessed by holding the control button for a few seconds (not preffered), or by accessing it through the network. Start a browser and enter the IP address (also found in the amplifier menu) 169.254.2.30 In the window choose “Band 2” instead of “Band 1”. (Preffered).

Start EMC32. Navigate to folder,” Daily_Check_Radiated_Immunity ”. Its location is
EMS Scan\ 0_Daily_Check.

Start the test by right clicking the relevant script and choose **New Test**.

When the test is completed an information window will pop-up. The information is about what parameters to check in the daily test. Make sure that the parameters are within accepted tolerances. If not, redo the test.

7.2 Appendix 2 - Software Setup for Measurement of Individual point

Measuring of E-field in the points is done in EMC32, which is the branch standard program from Rohde & Schwarz. Using the program for a test, there needs to be three files pre-defined. ***The hardware setup, the report setup and the test itself***.

Hardware Setup

In the hardware setup, the test equipment, signal paths and path losses are defined. It is a simple task to setup as all test equipment from Rohde & Schwarz is pre installed in the software. The signal paths are inserted as calibration files for the cables/paths that are used. EMC32 will do all signal path switching necessary if a frequency interval in the test setup would use different amplifiers etc.

Report Setup

In the report setup the data that is saved and plotted in an output file is chosen. As this thesis will execute experimental measurements, all available data is saved. The result of this did not affect testing time, only the report generation time by < 1 minute.

Test Setup

For the test setup, the following parameters have to be set. Frequency span, dwell time, step size, leveling mode and parameters monitored during test.

Frequency Span

Here the frequency spans are set. For this setup 1 – 10 GHz, there are two intervals. 1-6 GHz and 6 - 10 GHz.

Dwell Time

The dwell time is set to >100 ms as stated in theory. For product testing, the dwell time is set to a value greater than the cycle time of the running test checking all functions of the EUT.

Step Size

The step size of frequency in the entire spectrum is important to set correct. The EMC standards states logarithmic step size of 1% (IEC, 2006) (Telcordia Technologies, 2011). If another step size is used, the EUT could be under or over tested compared to the standards.

Leveling mode

The test can be run with different leveling parameters. It can be run with the E-field probe where the system tunes the output power to match a set E-field level measured by the probe. It can also be run with no probe and pre-recorded forward powers which is known to create the correct voltage at the measuring point. This is called running a reference calibration. When testing points if the system can create a strong enough E-field it is set to probe leveling. When running the test with an EUT then it runs of a calibration file with pre-recorded forward voltages.

Monitor Parameters

There are some parameters that are important to monitor during a test to make sure that there is no malfunction or possible danger to the test equipment. These are; Power out, Amplifier Saturation, VSWR, Field Probe Level.

Power Out

The power out should never exceed what level is specified of the amplifier. If it does, the amplifier could be overdriven due to a faulty set limit level.

Amplifier Saturation

The amplifier saturation level is the ratio of the power required to produce test level compared to modulation level. They differ by a factor 1,8 which corresponds to 5,1 dB using equation (7). If the saturation level falls below 3 dB, which is a specified limit in EN61000-4-3 then the amplifier is considered saturated and will produce a distorted, insufficient modulation. Figure 63 below illustrates the concept. The two operating points shall not be positioned too high on the amplifier saturation curve where the in/output power loses its linearity and starts to distort. The saturation is measured in dB and is some places defined as negative and other only as magnitude/positive.

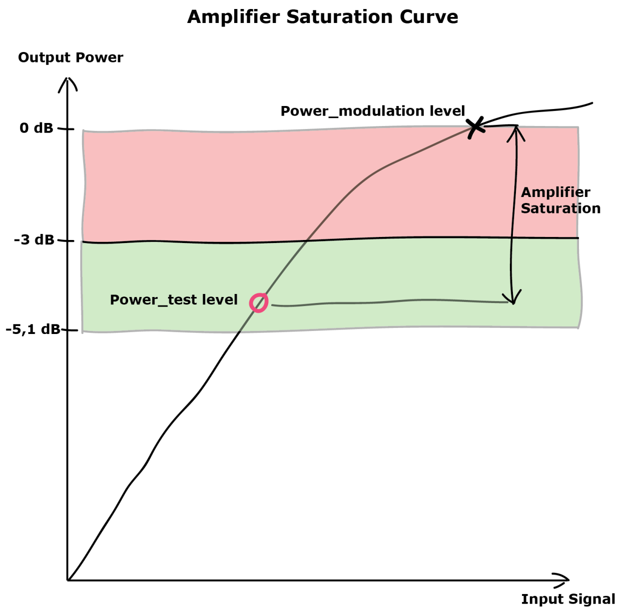


Figure 63: Illustration of amplifier saturation phenomena

VSWR

Too high VSWR could cause amplifier damage if the amplifiers do not have an integrated protection circuit. It could also signal a bad connection in the setup that would reflect power in the signal path and cause insufficient E-field at the UFA. A high VSWR will present an issue with the setup.

Field Probe Level

Is the reference file not achieving high enough E-field? This could address an issue in the practical setup of the test. Is antenna position incorrect?

7.3 Appendix 3 - Software Setup for UFA Calibration

Creating an Autotest for Calibration Measurements

A reference calibration file in EMC32 means to create a file, which is used as a leveling mode as described earlier in the theory section. A table which states amplifier forward power needed to assure that all points of the UFA reaches specified electric field strength level.

To calibrate a surface, an autotest is created as shown in Figure 64 below. An autotest is a test, which is programmable to loop certain measurements. Two autotests were created, one for 1-6 GHz and another for 6-10 GHz. There are multiple parameters of an autotest that needs to be created and input. According to the following procedure;

Autotest Settings

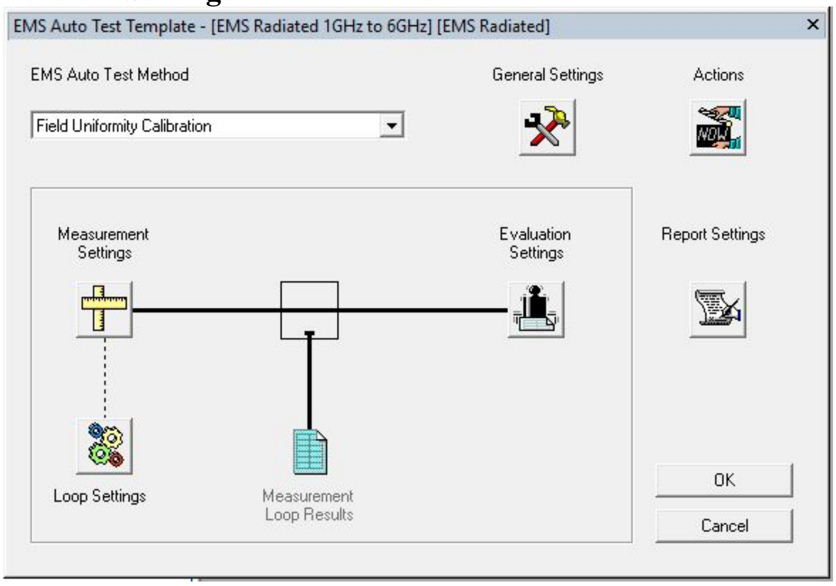


Figure 64: Autotest default window

In the autotest window shown above in Figure 64, a pre-defined measurement test has to be added in the measurement settings, this test is what defines what test will be looped, what frequencies tested and to what levels of field strength.

Autotest Measurement Settings

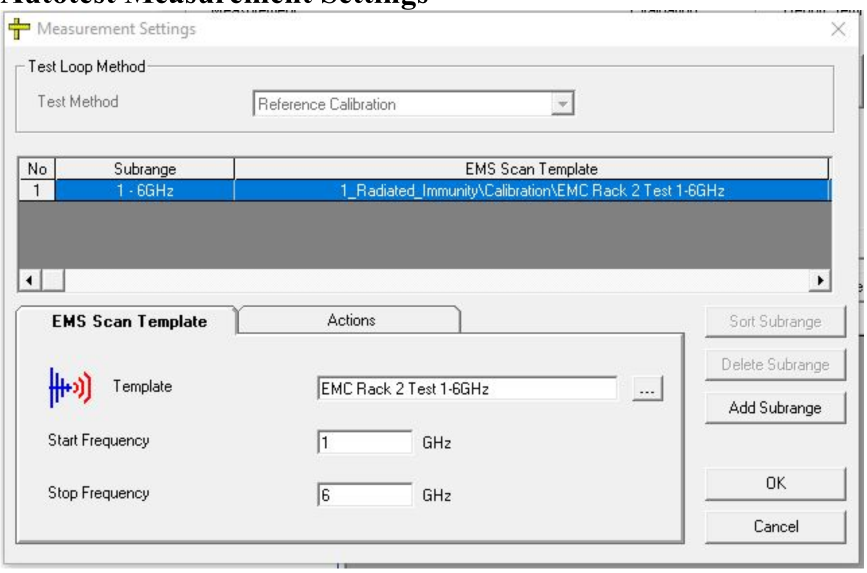


Figure 65: Autotest measurement settings

In the measurement settings shown in Figure 65 above, the test which shall be run is input, denoted “EMS Scan Template”

EMS Scan Template Settings

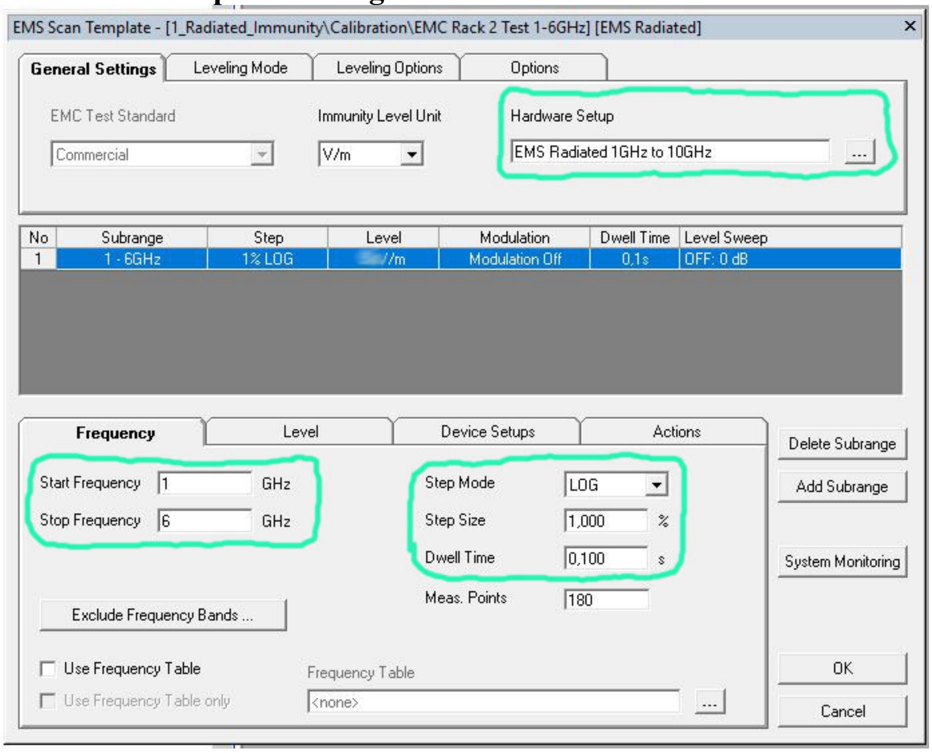


Figure 66: EMS scan template

In Figure 66 above, the frequency range is entered, what test level is tested, leveling mode set to probe, step size is logarithmic 1% just as standards specify and the dwell time is set to 100 ms according to theory.

The next autotest parameter to set is the ”Loop Settings”.

Autotest Loop Settings

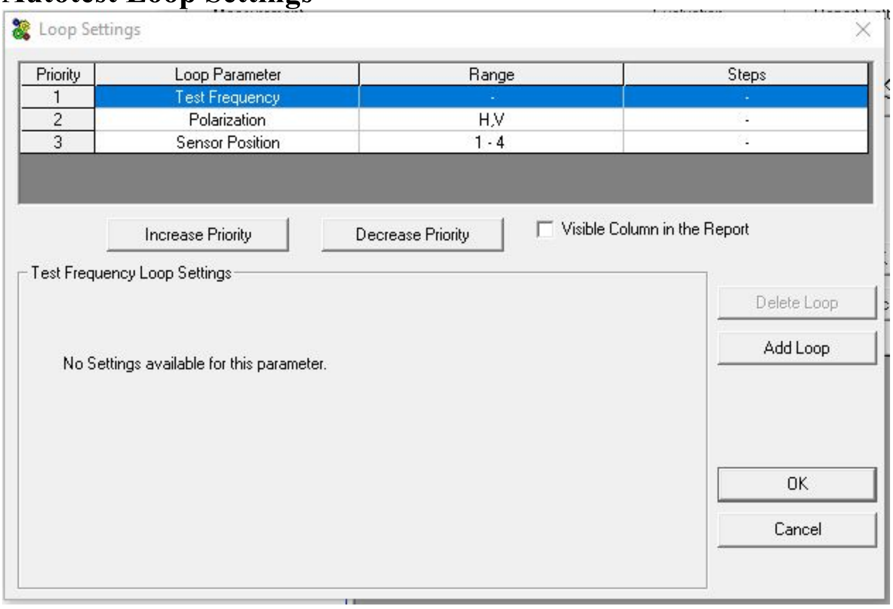


Figure 67: Autotest loop settings

In Figure 67 above, the actions that is to be looped is input. At highest priority is the frequency sweep measurement. This has to be done for both polarizations of antenna, horizontal and vertical. These two actions have to be repeated for every measurement point. For the 0,5 x 0,5 m UFA there are 4 test points, hence the range is point 1 to point 4.

The ”Loop” function is not logical to any sort of programming language, hence it looks strange in list form. The list is only input parameters for EMC32 to calculate the most efficient loop with fewest moves. The testing order with fewest moves is to start at point 1 and sweep for horizontal, rotate polarization, sweep for vertical, then it will prompt to enter the chamber and move the probe to position 2 where it will start a sweep in the same polarity as the last test and so on, so forth. This is to reduce testing time.

Lastly is the report setup.

Autotest Report Settings

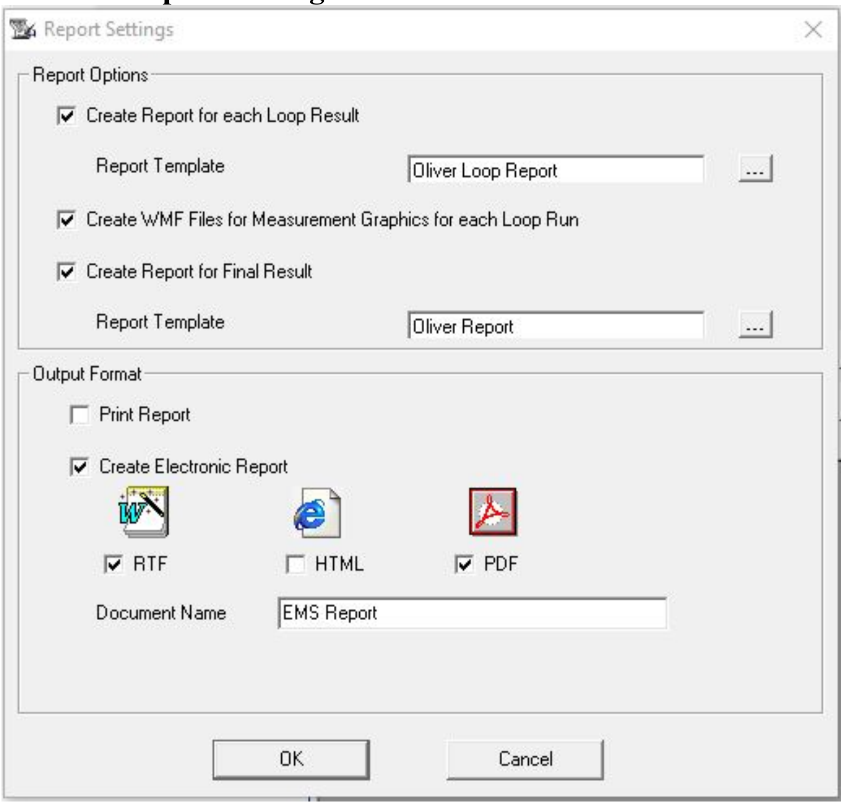


Figure 68: Autotest report setup

In Figure 68 above the pre-made report templates are entered. After the calibration is done, a report is created according to these specifications of what data to include. For this calibration, only data for this thesis needs to be saved. The report will not be used, unlike for a certified test house which always need to generate a test report and present data about the test setup.

Validating Results From Autotest Calibration

With all parameters of the Autotest set, the autotest was run and as previous results, all four points of the UFA reached the specified electric field level. And the calibration file was saved.

What also has to be checked is how the measuring points fulfil the uniformity demand (0,+6dB). This is done by creating a test as follows:

Calibration Validation Test Settings

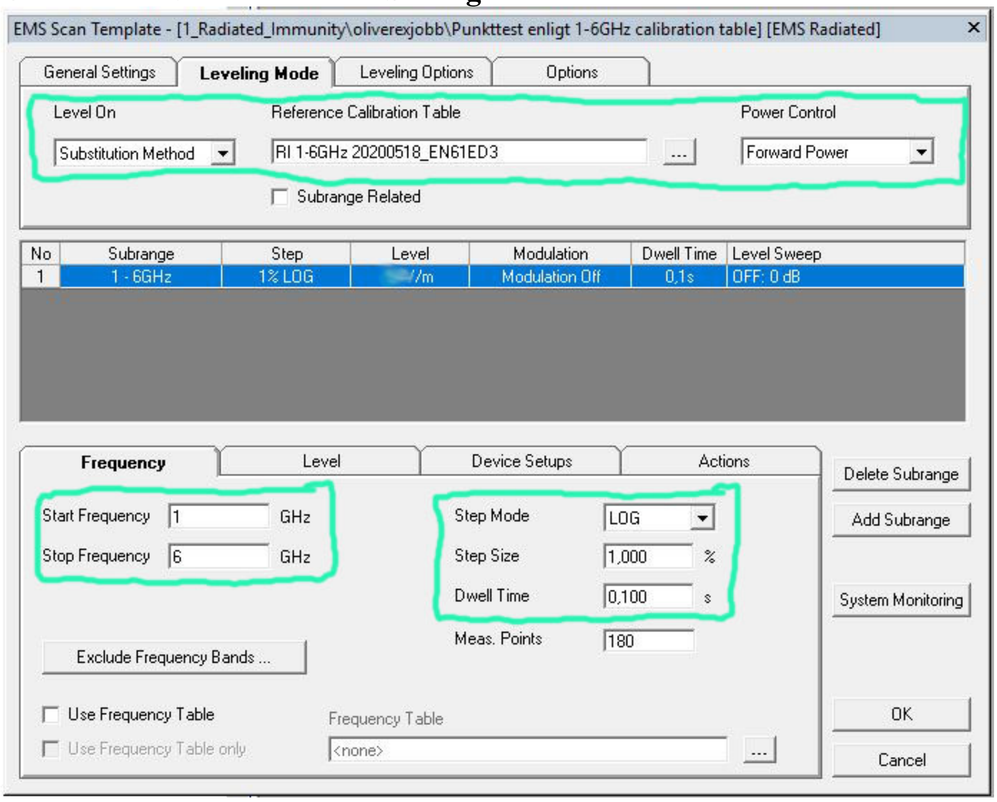


Figure 69: 1-6 GHz Calibrated test

In Figure 69 above, the frequency, step size and dwell time is the same as a regular test, however the leveling mode is now switched to substitution method and the calibration file is set as an input file.

Calibration Validation Measuring

This test was executed with leveling mode set to the forward power from the calibration file which means that all four measuring points of the UFA will at least reach the stated test level at all times of the sweep. This test was executed with the E-field measuring probe set at each calibration point. The data was then entered in Excel where all points can be compared in a plot to validate that all measuring points of the UFA is within the (0,+6 dB) test demand.

7.4 Appendix 4 - Ordering of Proper Cabling:

There are multiple parameters to be considered when ordering cables for the system. These include cost, length, connectors, attenuation, stiffness, power handling and breakdown voltage. The following parameters were discussed over the phone with Lars Wehlén at Rosenberger sales department (Wehlen, 2020).

Cost

The price of the cable is less relevant compared to other parameters such as attenuation, which is a key factor in choosing a cable for this application. Lars Wehlén at Rosenberger, which is the chosen supplier for cabling, was presented the application and pictures of the setup, which he responded to with reasonable cables pricings.

Length

The length of the cable is crucial because of attenuation properties, which grows at higher frequencies. Therefore the cable route should be as short as possible from PA to antenna. This is valid for every case except for when attenuation is needed to reduce return power of a bad VSWR and still push through a certain amount of forward power. This should not be the case since we have antennas with low SWR over the band.

Connectors

The connectors needs to be of the same kind as the RF out of the rack and the antenna being used as well as the through wall connectors in the chamber wall. This type is standard N-contacts. To the antenna there was chosen a N-connector with 90-degree elbow. This is because the antenna will turn between horizontal and vertical polarization. The connector on the antenna is near the mount and perpendicular to the axis of rotation. A 90 degree elbow will barely flex the cable with this setup, however if the cable would have been with a straight connector and stick out perpendicular to the axis of rotation there would be a need for a large cable slack to allow for the turning movement.

Attenuation

The attenuation of the cable should be as low as possible. This factor is often limited by flexibility of the cable and cost. A more rigid less "bendy" cable has lower attenuation but might not fit the desired placement. Flexible cables that have low attenuation do not go well in hand with cost. Therefore this is a compromise. Choosing a cable from flexibility, cost and tweaking your choice after attenuation is the reasonable choice.

Stiffness

The stiffness for our purposes was described and pictures sent to the supplier Rosenberger, which has good knowledge of their products. As a reference the light blue UFB293C that we have experience with earlier was said to fit the purpose good, being a little bit on the stiff side. Their response was that UFB293C would be our best option since the option with better qualities is stiffer, and a more flexible cable would have inferior properties regarding attenuation.

Power Handling and Breakdown Voltage

Power handling

This parameter is more difficult to choose cable from. Since the power through the cables varies with all the calibration points in the room, the throughput could be, 10 seconds of 15 watts, 10 seconds of 380 watts and then back to 10 watts. The cable classifications are from tested power at CW for a certain period of time. The cable will of course allow a higher power for a shorter period of time, just as the characteristics of a radiated immunity test. This decision was given to Lars Wehlén at Rosenberger, which has extensive experience with their cables and limitations. For the case of this thesis, the UFB293C was considered sufficient.

Breakdown voltage

The consultant Per Isacsson who installed the rack had a rule to check the datasheets of the cables for the maximal voltage caused by the PA will not ruin the cable for worst case scenario, unlimited VSWR. In the case of unlimited VSWR all power is reflected and the peak voltage that will appear on the cable is the sum of the peak forward voltage and the peak reflected voltage, which will be the same if no loss is considered.

As calculated in the Theory section – Overvoltage in Cabling, the highest voltage that can arise is 400 V between inner and outer conductors in the coaxial cable. (Rosenberger, 2014)

7.5 Appendix 5 - Placement of Antenna (Distance to UFA)

2,20 m

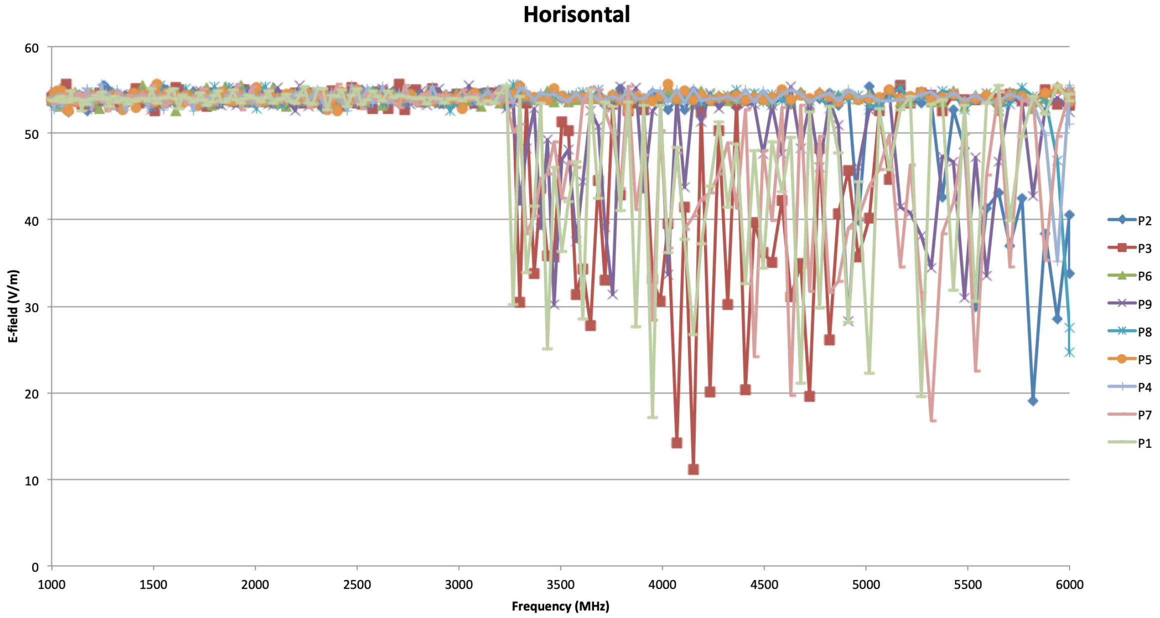


Figure 70: Electric field strengths at 2,2 m distance to UFA. Horisontal polarisation

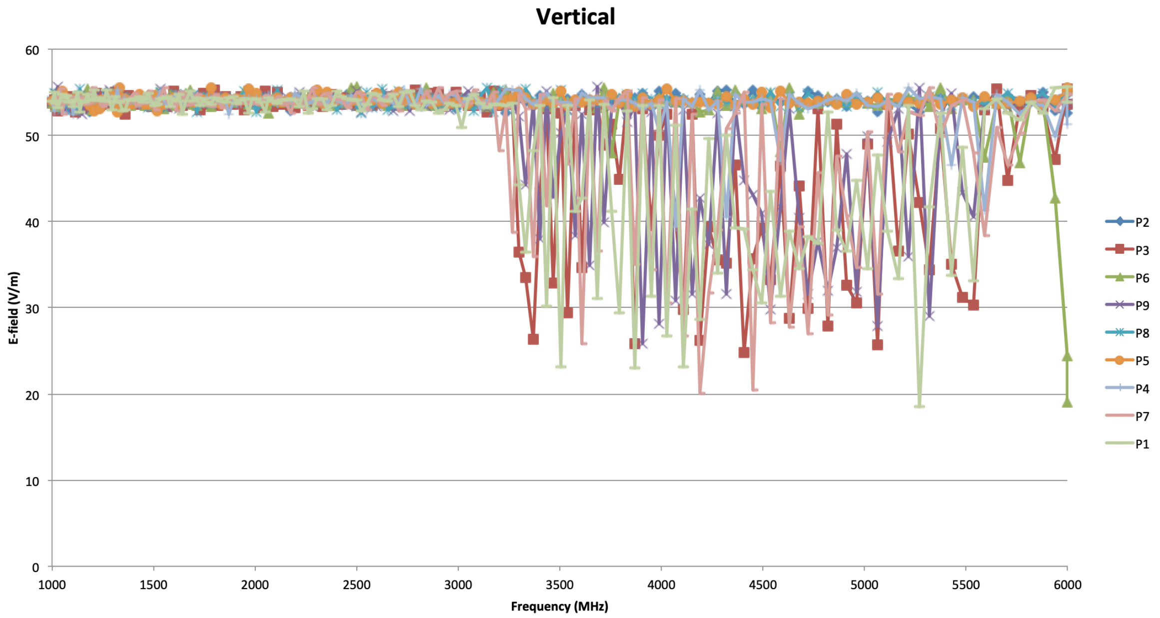


Figure 71: Electric field strengths at 2,2 m distance to UFA. Vertical polarization

In the previous two graphs Figure 70 and Figure 71 it is seen that X V/m is easily reached from 1 to 3,3 GHz where the phased 400 W amplifier combo is active. From 3,3 GHz to 6 GHz the 100 W amplifier does not achieve high enough field strength and the points will not meet internal test levels. Carefully examining this same data by individual rows of points shows that that the most troublesome points are the corner points, upper points and lower points.

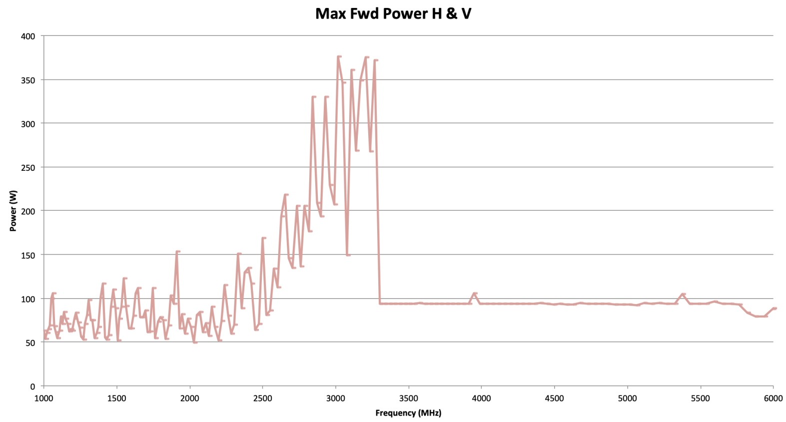


Figure 72: Fwd power of 2,20 m test

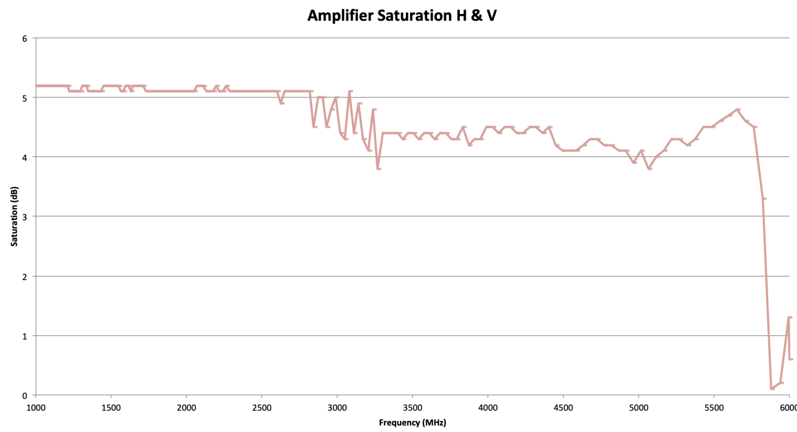


Figure 73: Amplifier saturation of 2,20 m test

From the above two figures Figure 72 and Figure 73 it is seen that the full amplifier power potential of 400W is never fully used up to around 2,7 GHz where it peaks up to 375 W and from 3,3 – 6 GHz all power from the 100 W amplifier is used.

3,00 m

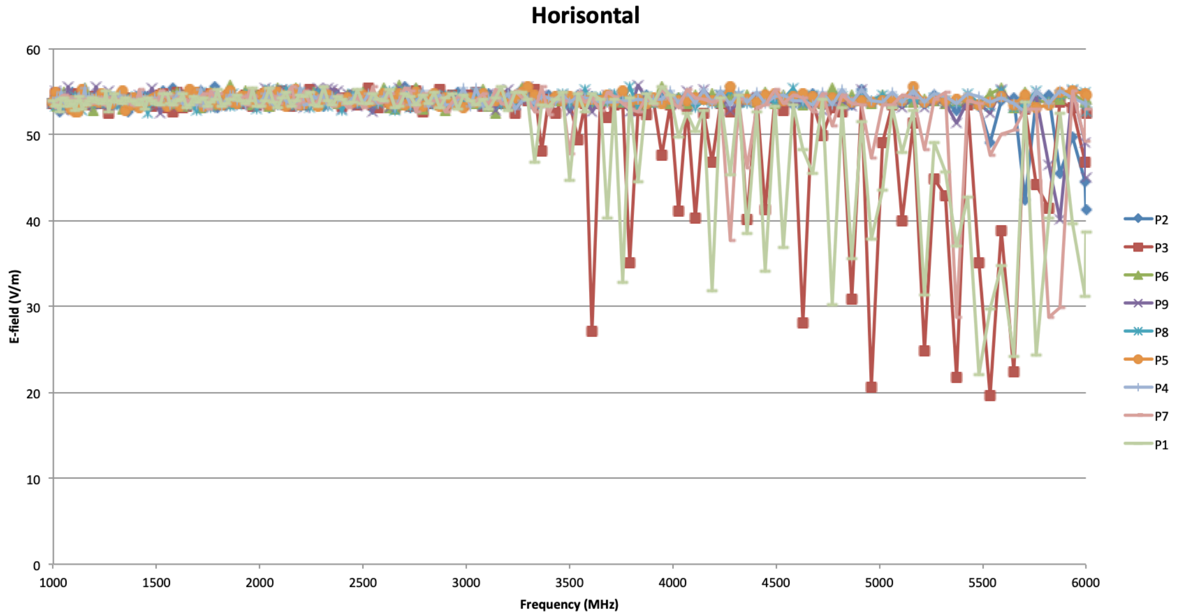


Figure 74: Electric field strengths at 3,0 m distance to UFA. Horizontal polarisation

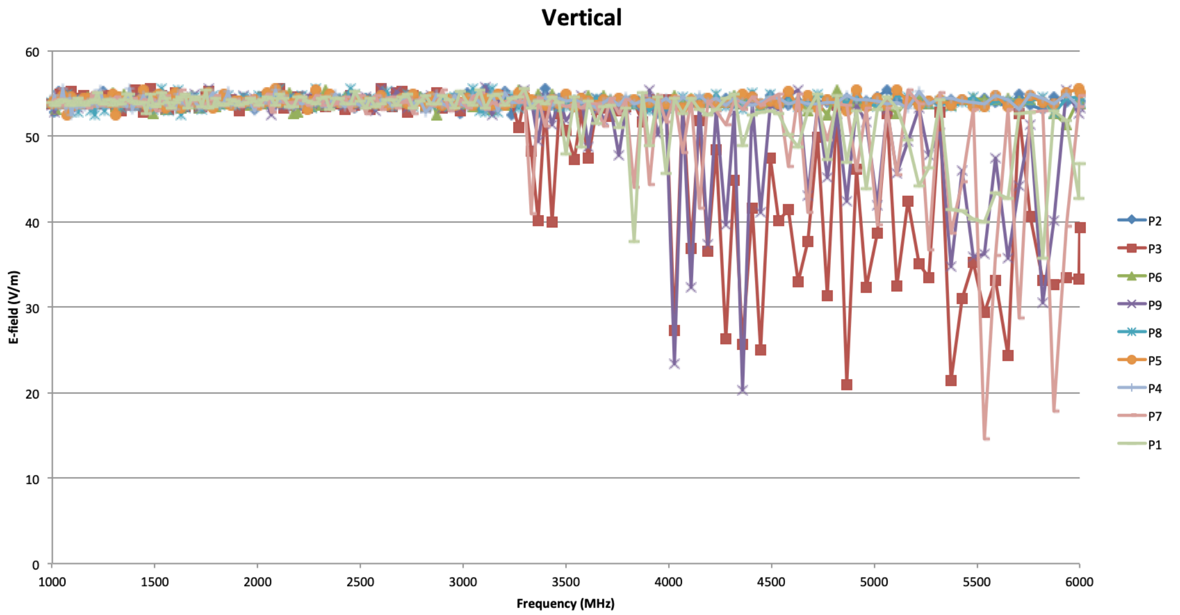


Figure 75: Electric field strengths at 3,0 m distance to UFA. Vertical polarisation

The field strength results from 3,00 m distance are presented in figure Figure 74 and Figure 75 above and are better than of the 2,20 m. The E-field dips for every point are not as deep and frequent as before. This is clearly seen by comparing the results for horizontal and vertical polarization in Figure 72 vs Figure 74 and Figure 73 vs Figure 75. Improved performance is shown in the middle side points, 2, 4, 6, & 8. The results show that moving the antenna backwards has allowed the UFA to step in the beamwidth and homogenous field to a greater extent.

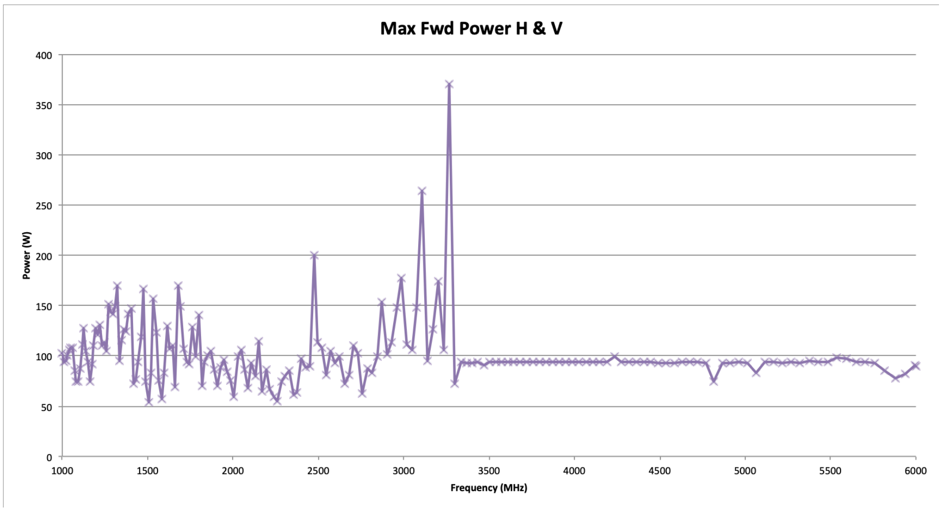


Figure 76: Fwd power of 3,0 m test

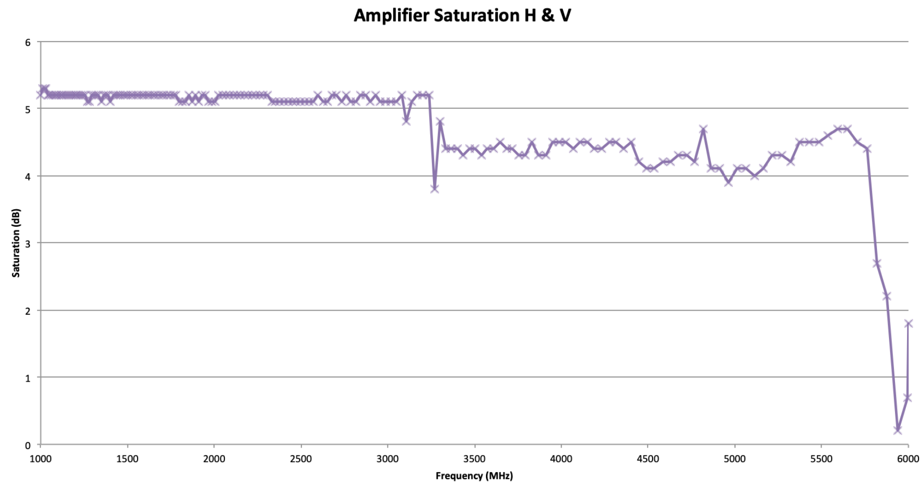


Figure 77: Amplifier saturation of 3,0 m test

As seen in Figure Figure 76 and Figure 77 above, the power for frequencies below 3 GHz has now increased since the antenna moved further back. Just according to the theory. However, the full power potential is only used at frequencies above 3,3 GHz. For this setup we are never in the reactive near field <1 m, however at frequencies under <1,8 GHz we are in the radiative near field. However, none of the results indicate any difference around 1,8 GHz, which would support the statement in theory that the boundaries are quite diffuse when combined in a single formula, which is applicable to all types of antennas.

By comparing results to theory and using equation (7) with a distance of 3,0 m it is seen that the opening angle to cover the entire UFA is 26,6 degrees and corresponds in the specification that our -6 dB limit is lost above 2,5 GHz since the gain lobe decreases with higher frequency as stated in theory. In Figure 76 above of the power it is seen that the forward power required increases significantly above 2,5 GHz. This behaviour would confirm the calculations that the gain lobe of BBHA9120J does not cover the UFA at frequencies over 2,5 GHz.

From this test conclusions are drawn that moving the antenna further from the UFA results in better electric field strength generation and less stress on the amplifiers, because of enclosing the UFA in our gain lobe to a greater extent than at 2,20 m. However, the results are not satisfactory, a larger distance must be tested.

3,50 m

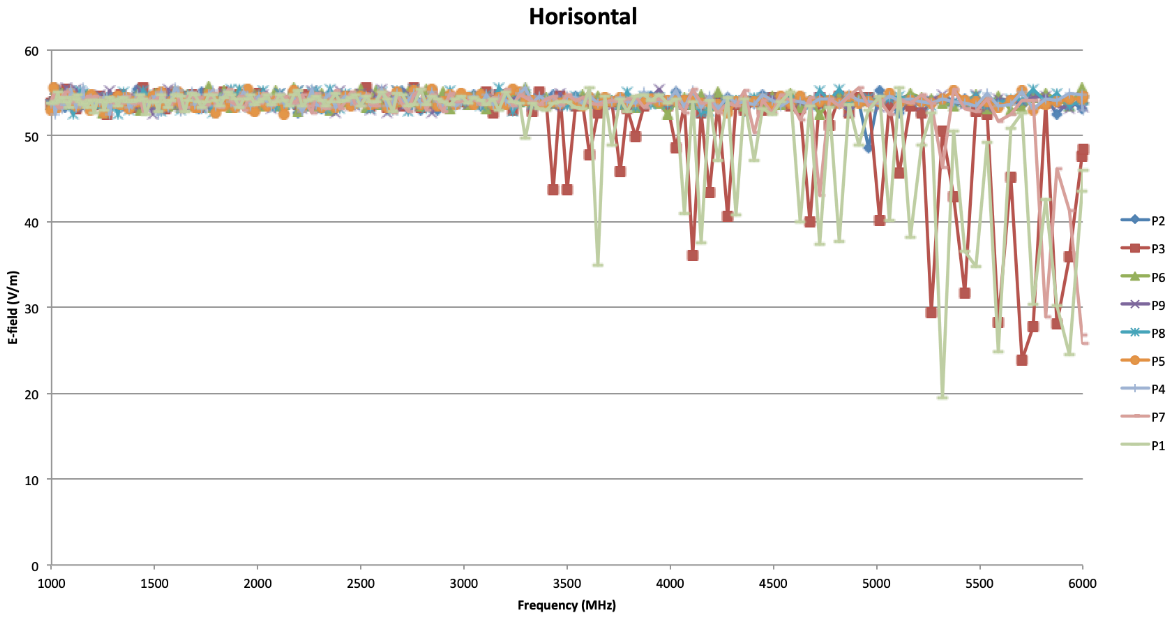


Figure 78: Electric field strength at 3,5 m distance to UFA. Horizontal polarisation

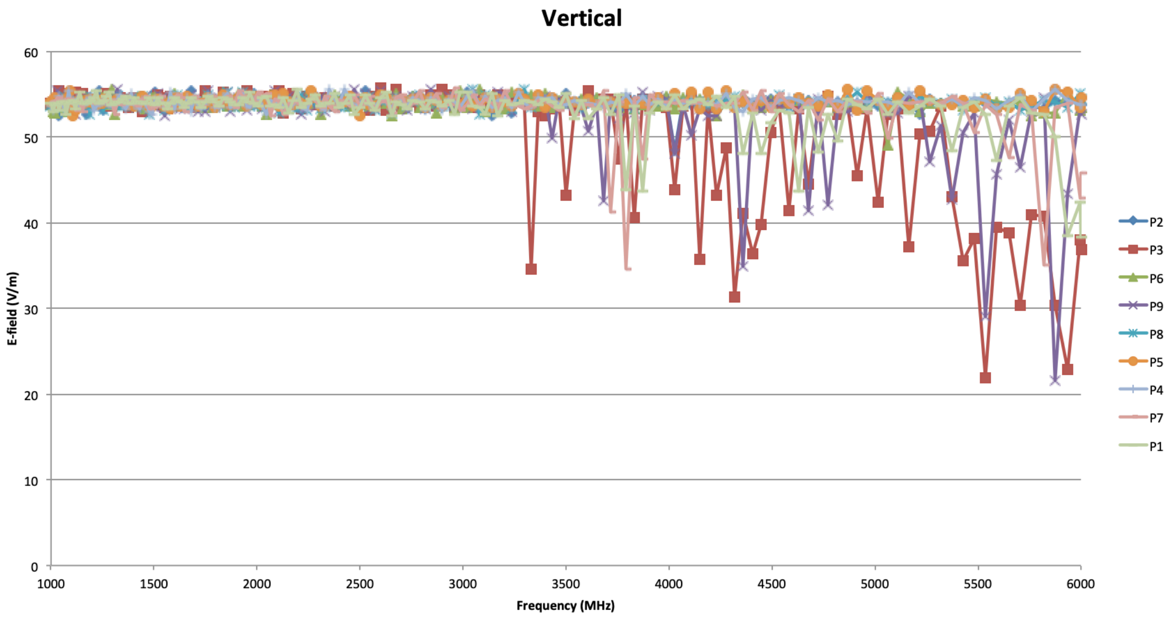


Figure 79: Electric field strength at 3,5 m distance to UFA. Vertical polarisation

Comparing the distance 3,50 m to both 2,20 and 3,00 m the results are significantly better. The dips in E-field are fewer and smaller as well as not affecting as many points as seen in Figure 78 and Figure 79.

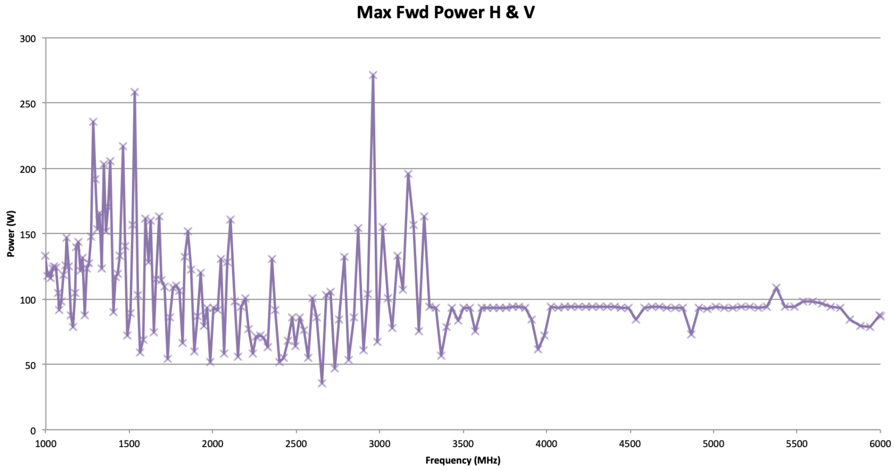


Figure 80: Fwd power for 3,50 m test

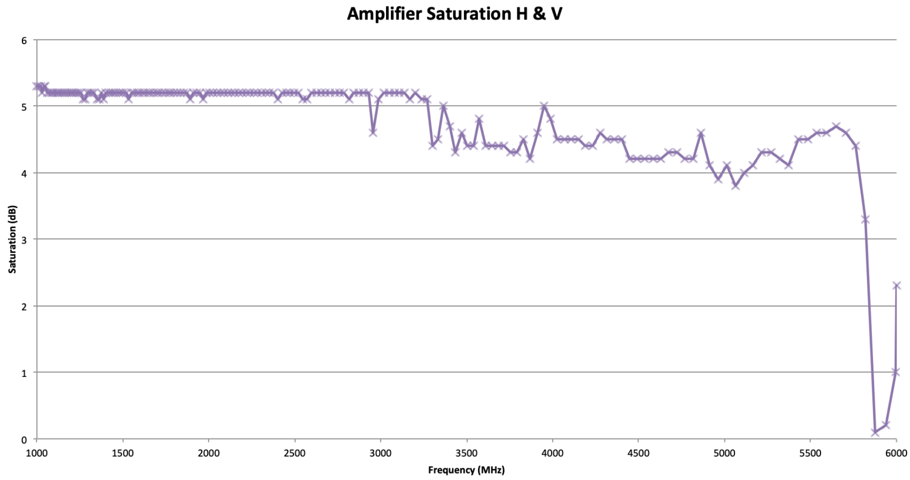


Figure 81: Amplifier saturation for 3,50 m test

By studying the power and amplifier saturation above in Figure 80 and Figure 81 the same behaviour as earlier is apparent. A generally higher power level due to increased distance between antenna and UFA is recorded. Lower peak power demands under 3 GHz due to more area in the gain lobe at frequencies now up to 3,0 GHz instead of 2,5 GHz. The 100 W amplifier from 3,3 – 6 GHz is still constantly supplying full power, but now with some dips.

7.6 Appendix 6 - Utilization of extra dampening cones

Dampening Cones Underneath UFA

A test where extra cones were inserted on the floor according to the Figure 57 above was carried out and two different points were compared. Point 3 and 9 was tested to have two points with different height above the cones. Figure 82, Figure 84 Figure 84 and Figure 85 shows the measurement results for point 3. Figure 86, Figure 87, Figure 88 and Figure 89 shows the results for point 9.

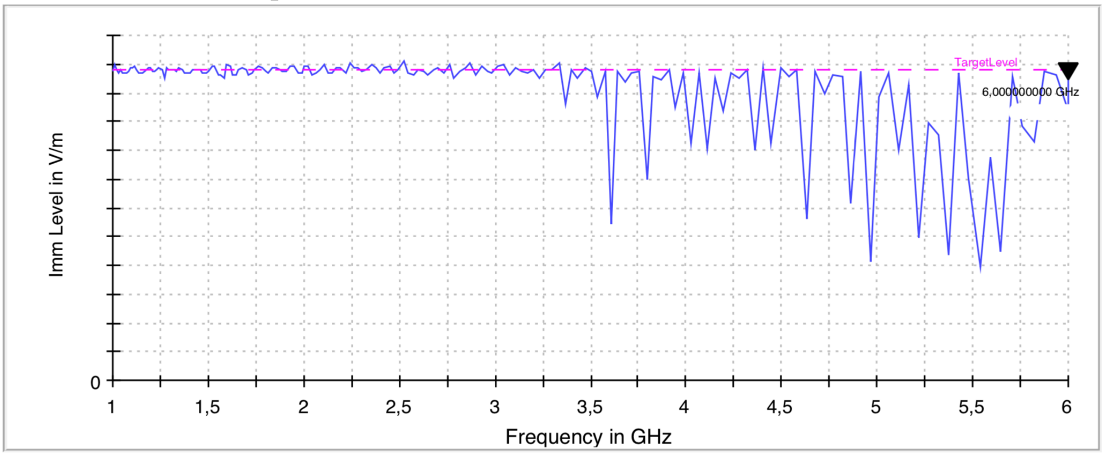


Figure 82: Measuring point 3 with no cones, 3,0 m distance to UFA, Horizontal polarization

Figure 83: Measuring point 3 with no cones, 3,0 m distance to UFA, Vertical polarisation

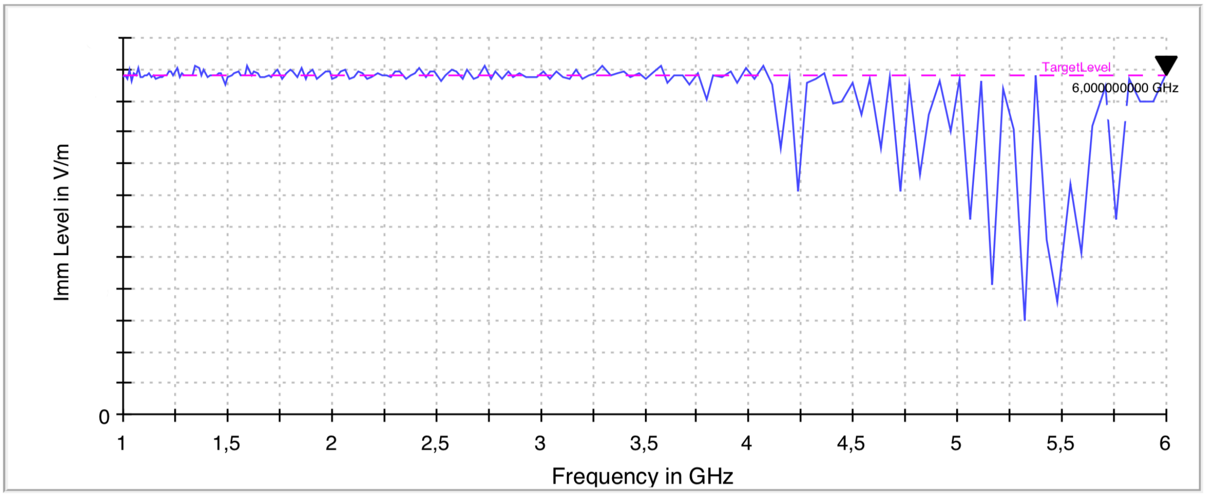


Figure 84: Measuring point 3 with cones under, 3,0 m distance to UFA, Horizontal polarisation

Figure 85: Measuring point 3 with cones under, 3,0 m distance to UFA, Vertical polarisation

For measuring point 3, the results for horizontal polarisation with cones seems to reduce the overall amount of dips in E-field but enforce some dips and making them dip further. This result is not better, yet not worse. It is equally bad from two different perspectives.

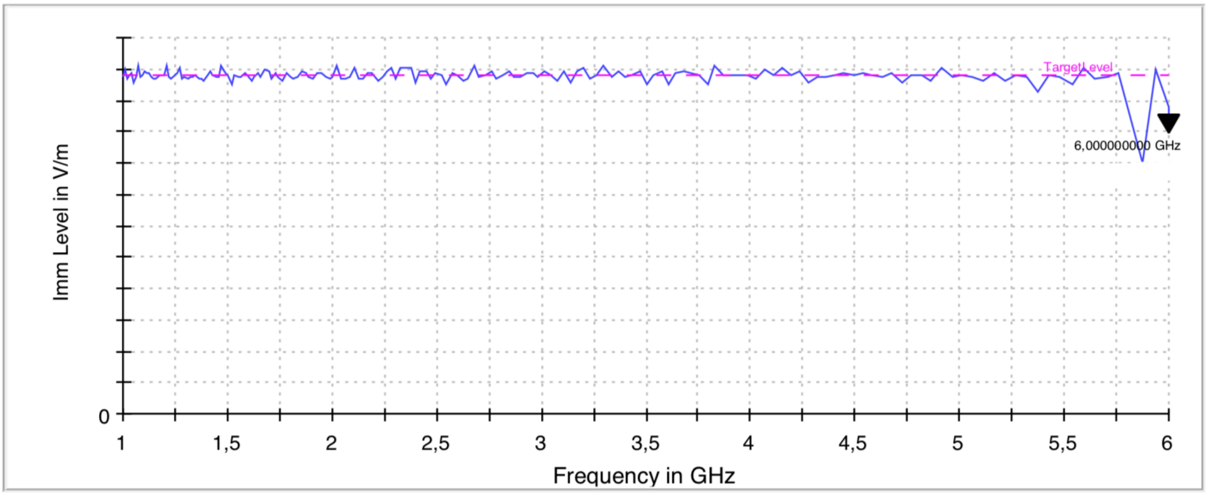


Figure 86: Measuring point 9 with no cones, 3,0 m distance to UFA, Horizontal polarisation

Figure 87: Measuring point 9 with no cones, 3,0 m distance to UFA, Vertical polarisation

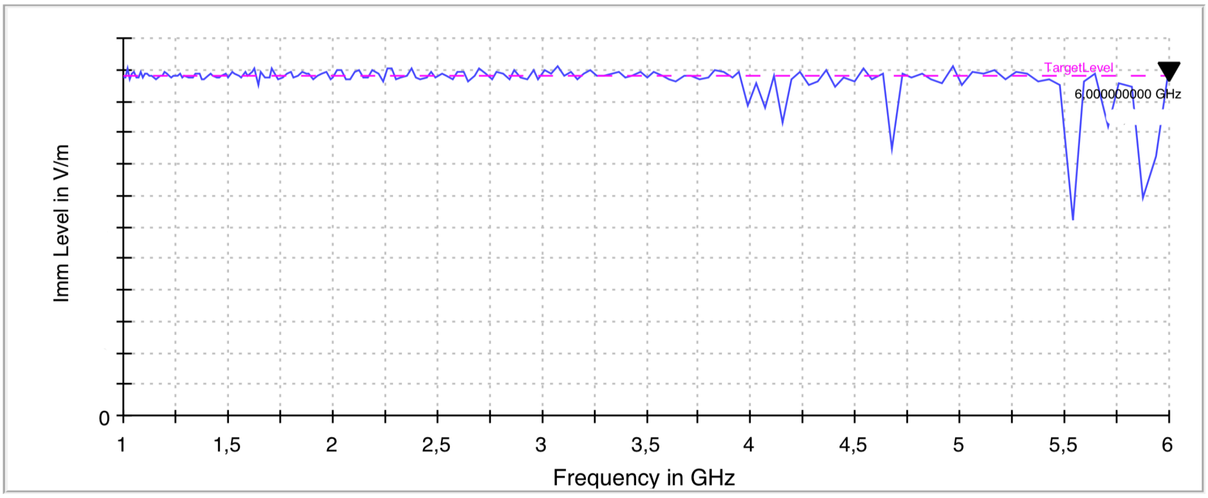


Figure 88: Measuring point 9 with cones, 3,0 m distance to UFA, Horizontal polarisation

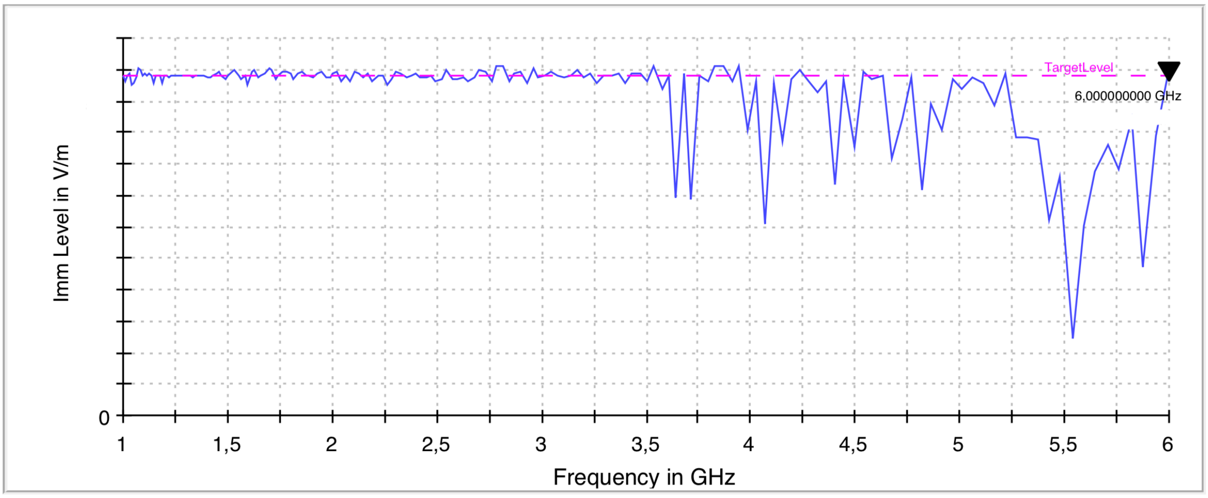


Figure 89: Measuring point 9 with cones, 3,0 m distance to UFA, Vertical polarisation

As seen when comparing Figure 86, Figure 87, Figure 88 and Figure 89 it is seen that adding cones underneath measuring point 9 created heavier dips than not having cones for both horizontal and vertical polarisation. However, having cones underneath in the vertical polarization decreased some peaks but instead spread them out over a larger frequency interval, as also seen in the results from measuring-point 3.

Dampening Cones Behind UFA

Point 9 was also measured when moving the cones from underneath according to Figure 57 to behind the UFA to cover the area near the floor/wall corner. Results are presented in Figure 90 and Figure 91 below.

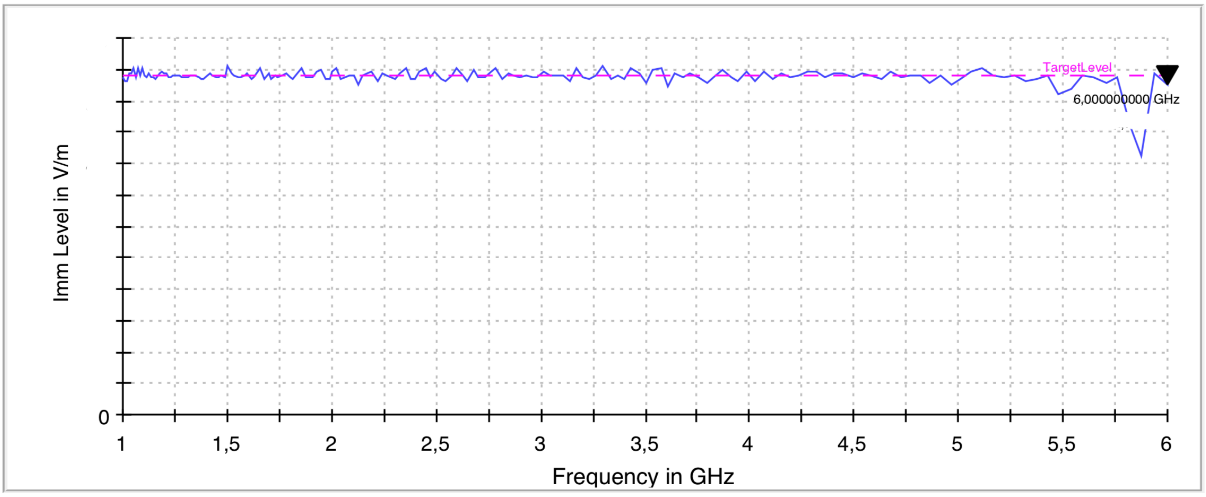


Figure 90: Measuring point 9 with cones at back, 3,0 m distance to UFA, Horizontal position

Figure 91: Measuring point 9 with cones at back, 3,0 m distance to UFA, Vertical polarisation

As seen when comparing the results in Figure 86 to Figure 90 and Figure 87 to Figure 91, the addition of having cones at the back of the chamber did not change the results noticeable from having no cones in the chamber at all.

From this it can be concluded that the addition of cones on the floor of the chamber does not favour the result or alter it considerably. However, it shows that reflections in the chamber can cause destructive interference and reduce E-field level with half of its magnitude. The overall results of this action of rearranging cones are henceforth not interesting to investigate further.

7.7 Appendix 7 - Placement of Antenna (Angular Displacement)

10 degree offset

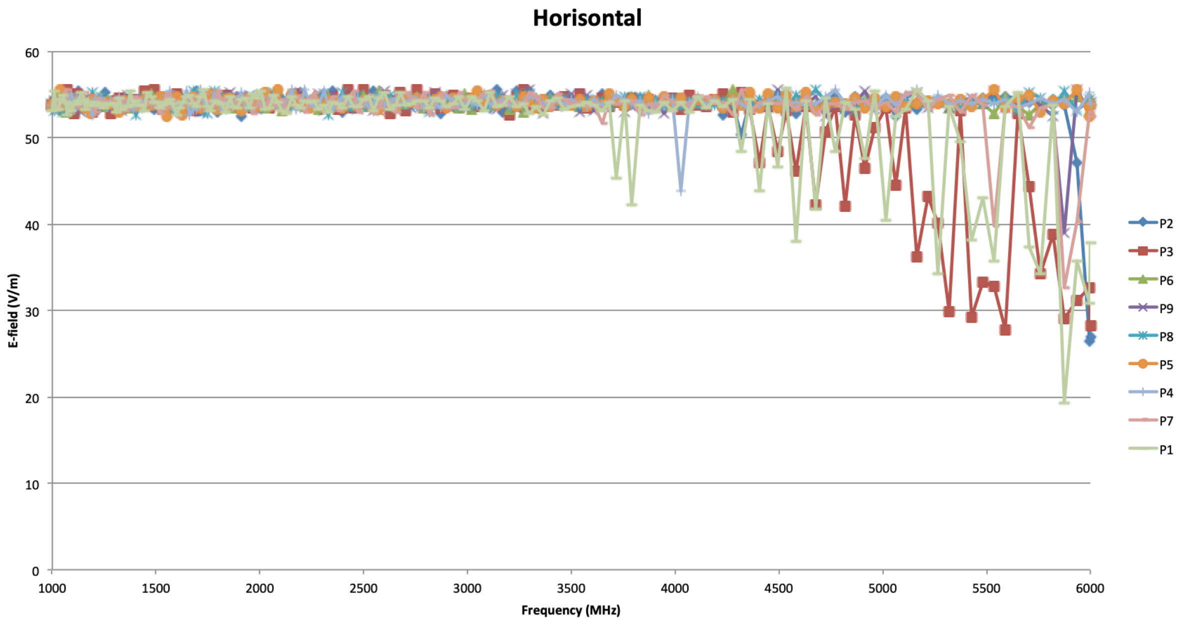


Figure 92: Electric field strength at 3,5 m distance to UFA, 10-degree offset horizontal polarisation

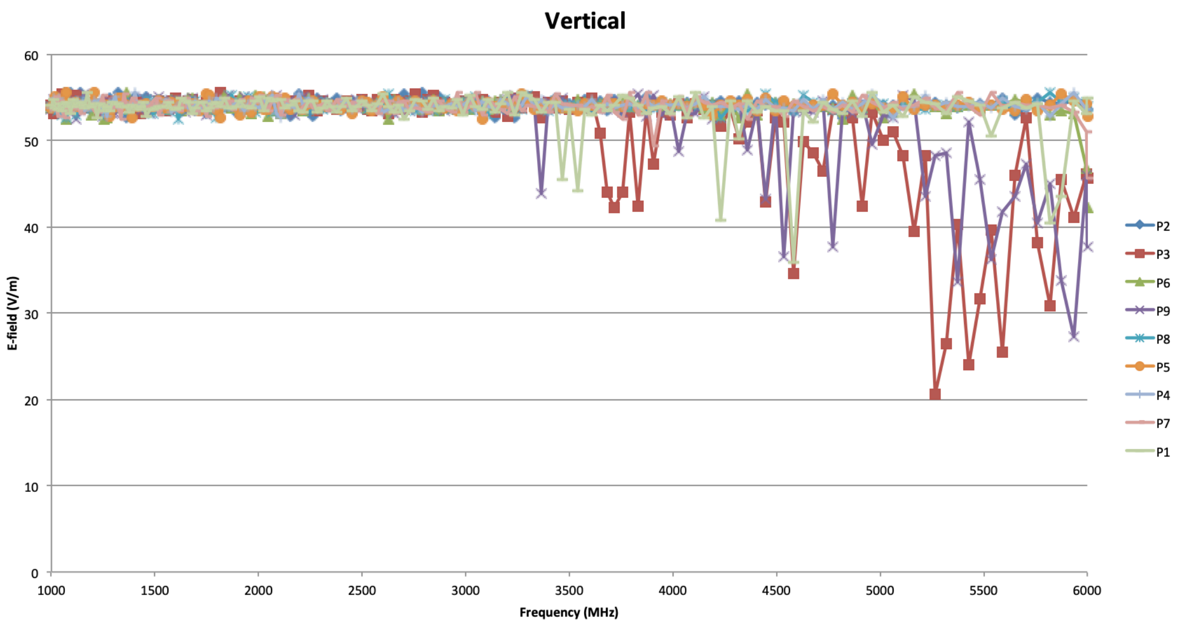


Figure 93: Electric field strength at 3,5 m distance to UFA, 10-degree offset vertical polarisation

The results from introducing an angle of 10 degrees show in Figure 92 and Figure 93 compared to those with 0-degree angle in Figure 78 and Figure 79, shows that this setup with 10 degree offset is significantly better in delivering higher levels of E-fields. However there were still points that were very troublesome Especially 1, 3 & 9. Point 7 had only a small amount of dips. These are the corner points that have difficulty being included in the beamwidth of the antenna as the opening angle decreases with higher frequencies.

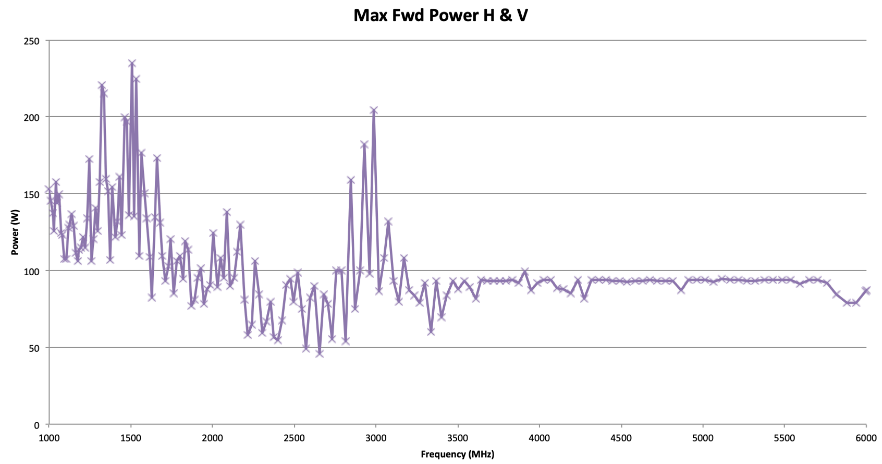


Figure 94: Fwd power for 10-degree offset test

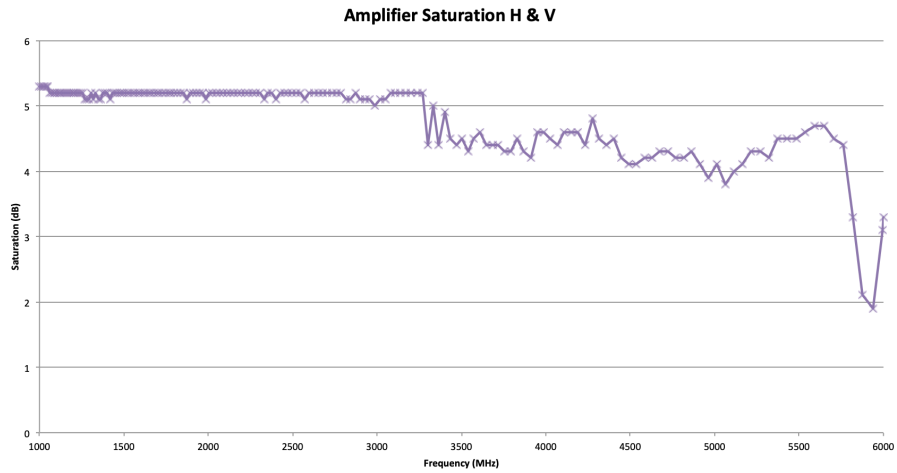


Figure 95: Amplifier saturation for 10-degree offset test

If the power required for 3,50m 0-degree and 10-degree is compared in Figure 80 to Figure 94 it is seen that the general power level is the same, however the worst peaks reaching 260 & 270 W in 0-degree decreased to 230 & 210 W with 10-degree offset. Approximately an average decrease of 50 W. This behaviour validates the theory of eliminating symmetrical reflections and rear wall reflections.

The same general power level excluding peaks stays the same since there was no change in distance to UFA.

From this it can be concluded that adding an offset angle helps to eliminate symmetrical reflections and rear wall reflections from causing destructive interference.

15 degree offset

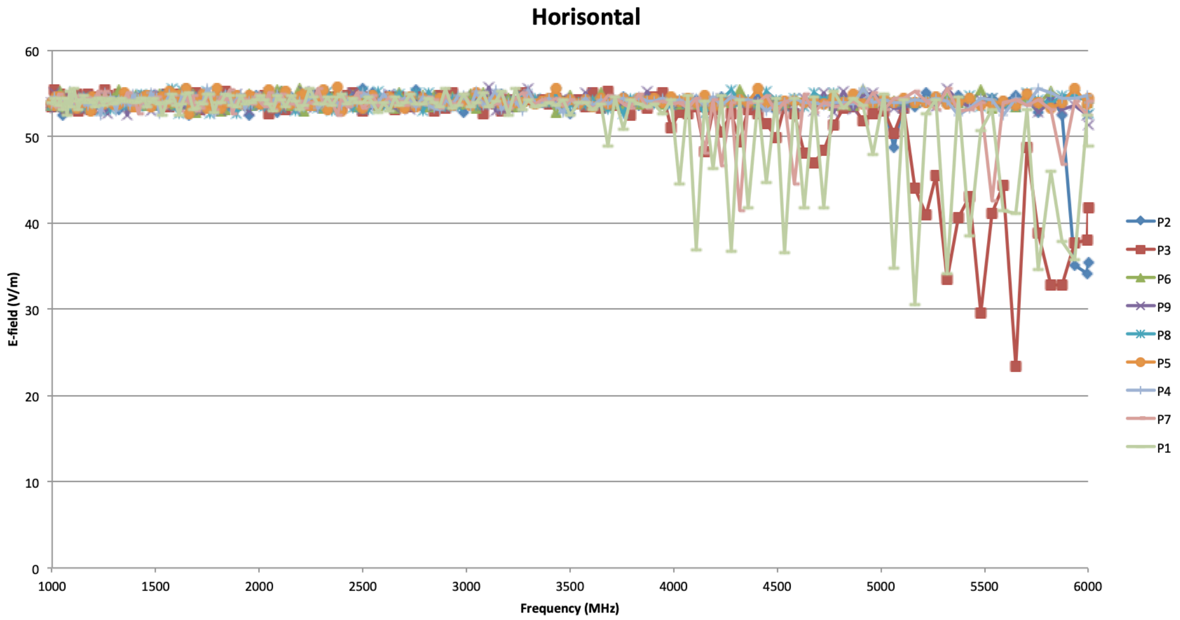


Figure 96: Electric field strength at 3,5 m distance to UFA, 15-degree offset horizontal polarisation

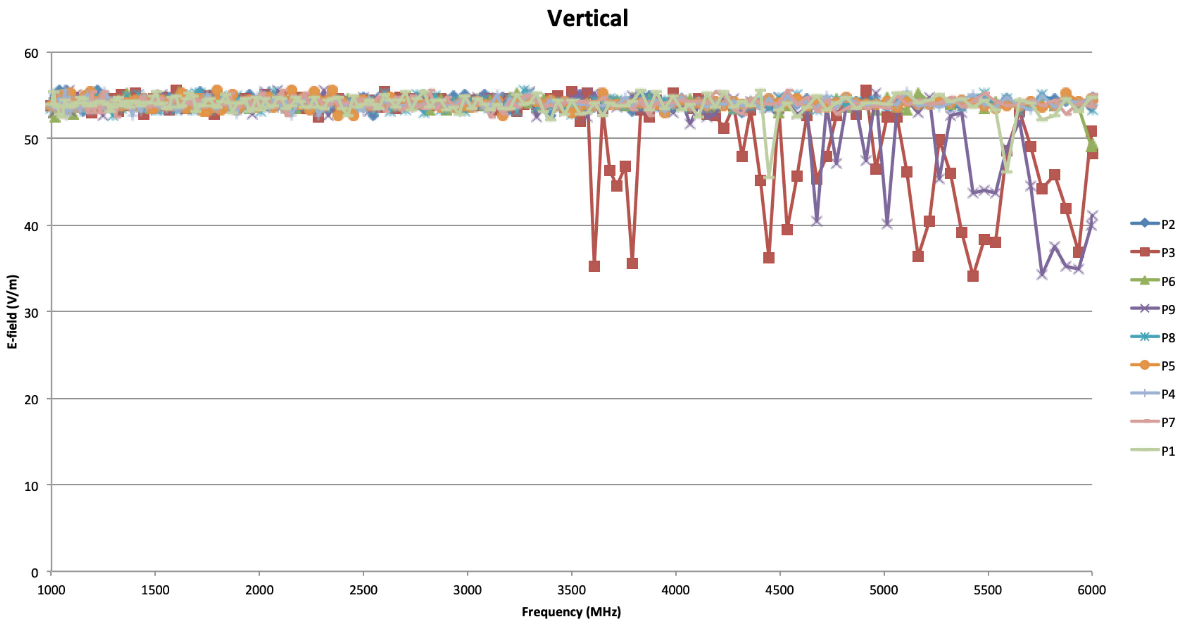


Figure 97: Electric field strength at 3,5 m distance to UFA, 15-degree offset vertical polarisation

The results from 15 degree angular offset in Figure 96 and Figure 97 was better than 0 and 10-degree offset. The dips in electric field are not as deep as for 0 and 10-degree offset. The results also show points that remove all dips, e.g. point 1 in vertical polarisation.

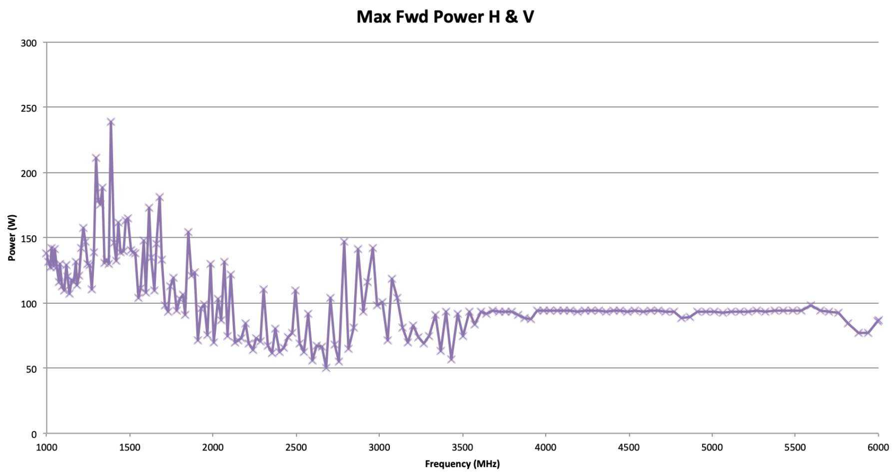


Figure 98: Fwd power for 15-degree offset test

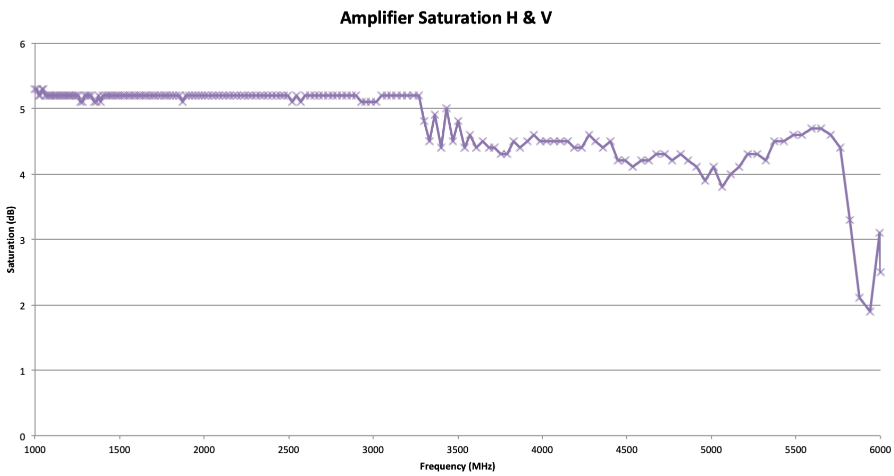


Figure 99: Amplifier saturation for 15-degree offset test

Comparing the forward power for 10 degree offset to 15 degree offset in Figure 94 to Figure 98 it is seen that the same behaviour as the previous change from 0-degree to 10-degree. The general power curve is similar and the differences are shown in the peaks. They tend to decrease from around 200 W to 150 W at an average of 50 W.

From this it is concluded that the best results so far was obtained with this setup, all according to theory.
This gives two conclusions,
1 - The maximum angle of 15 degrees together with maximum distance between antenna and UFA of 3,5 m produces the best results at the turning table.
2 - It is impossible with the current setup to produce a 1,0 x 1,0 m UFA at the turning table.

7.8 Appendix 8 - Placement of UFA - Distance to Back Wall

Closer to Antenna < 3,0 m

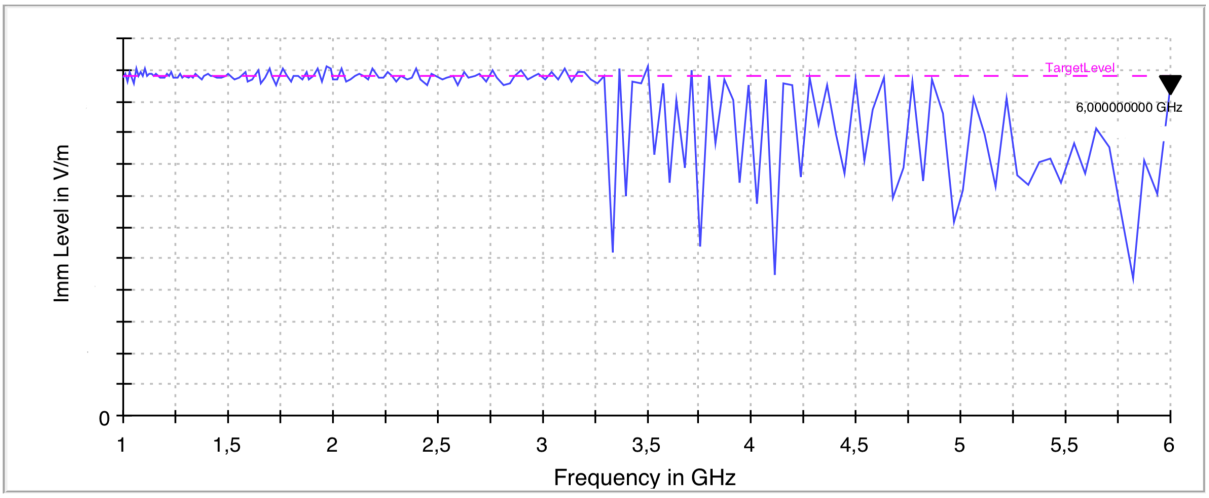


Figure 100: Electric field of Measuring point 7, UFA closer to antenna <3,0 m, Horizontal polarisation

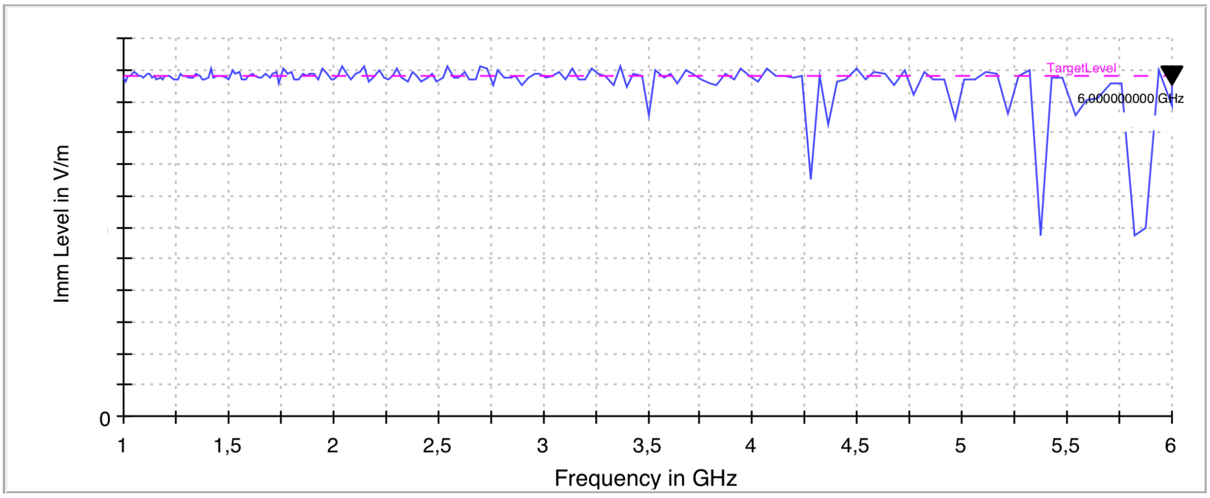


Figure 101: Electric field of Measuring point 7, 3,0 m, Horizontal polarisation

From figure Figure 100 and Figure 101 above it is seen that bringing the UFA closer produced worse results since it very clearly does not fit within the gain lobe of the antenna.

Further From Antenna > 3,0 m

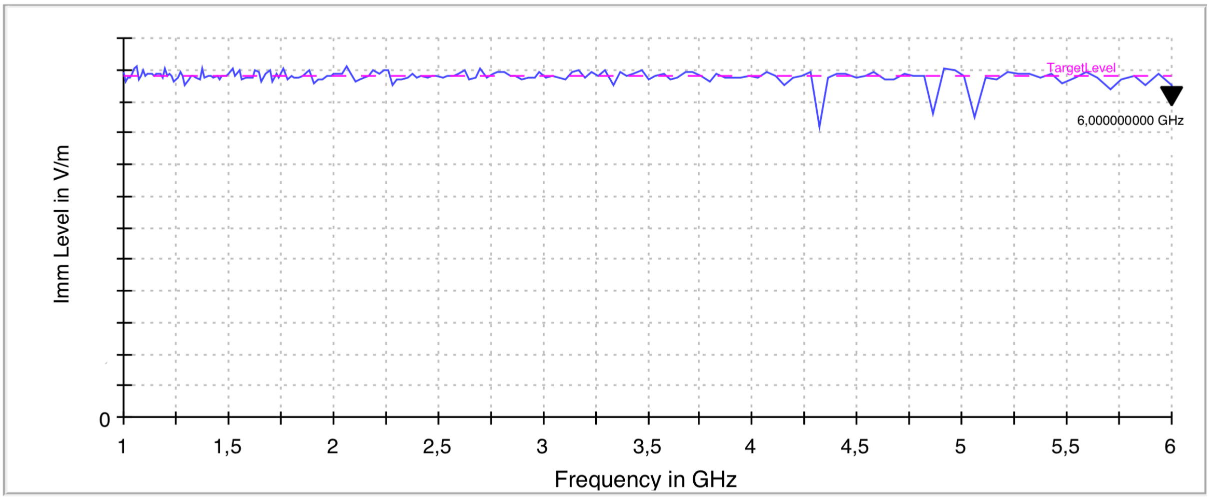


Figure 102: Electric field of Measuring point 7, UFA further from antenna >3,0 m. Horizontal polarisation

As seen when comparing Figure 101 to Figure 102 above, it is clear that moving the UFA further away from the antenna to the back of the chamber strongly reduces lack of performance in reaching internal field level specifications. This is the same result that was obtained by moving the antenna closer/further to the UFA in the first measurements.

7.9 Appendix 9 - Distance 4,3 m from antenna

From these results, the furthest extreme was tested to examine the possibility of finding a 1,0 x 1,0 m UFA. With just enough space at the back to allow the standard baseband depth + any cabling to bend upward/downward without touching the cones on the rear wall the UFA was placed at a distance of 4,3 m from the antenna at a 15 degree offset. This measurement is the absolute furthest distance possible to achieve in this chamber with the antenna attached to the Frankonia antenna tower. Since the area had 9 calibration points, two of them can violate the (0,+6dB) uniformity demand.

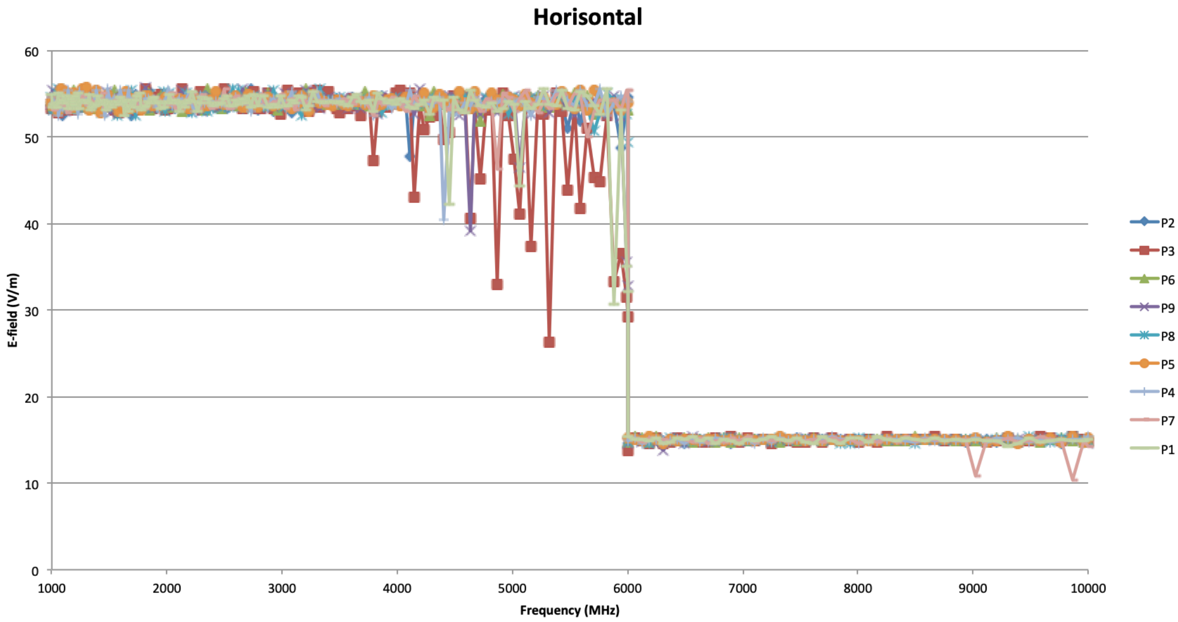


Figure 103: Electric field of 4,30 m 15-degree 1,0 x 1,0 m UFA horizontal polarisations

In Figure 103 the red point 3 does not achieve the test level strength. Colour purple and green, point 9 and 6 show some dips that would violate the demand as well.

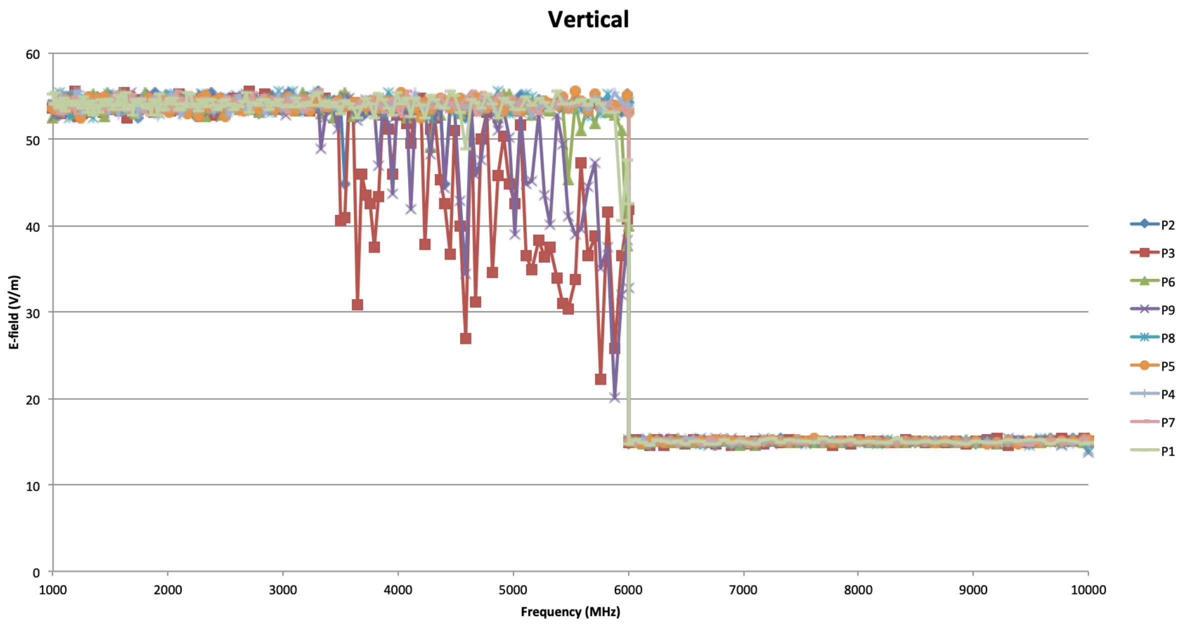


Figure 104: Electric field of 4,30 m 15-degree 1,0 x 1,0 m UFA vertical polarisations

As seen in Figure 103 and Figure 104 above, point 3 and 9 violate the uniformity demand and point 1 shows very minor violations that would only affect the modulation and could possibly disappear with new optimal cabling for the setup. Achieving a 1,0 x 1,0m UFA at this position is on the verge of what is possible in this chamber with these antennas. Since the UFA still was not in the gain lobe the area does not fulfil the demands of EN-61000-4-3.

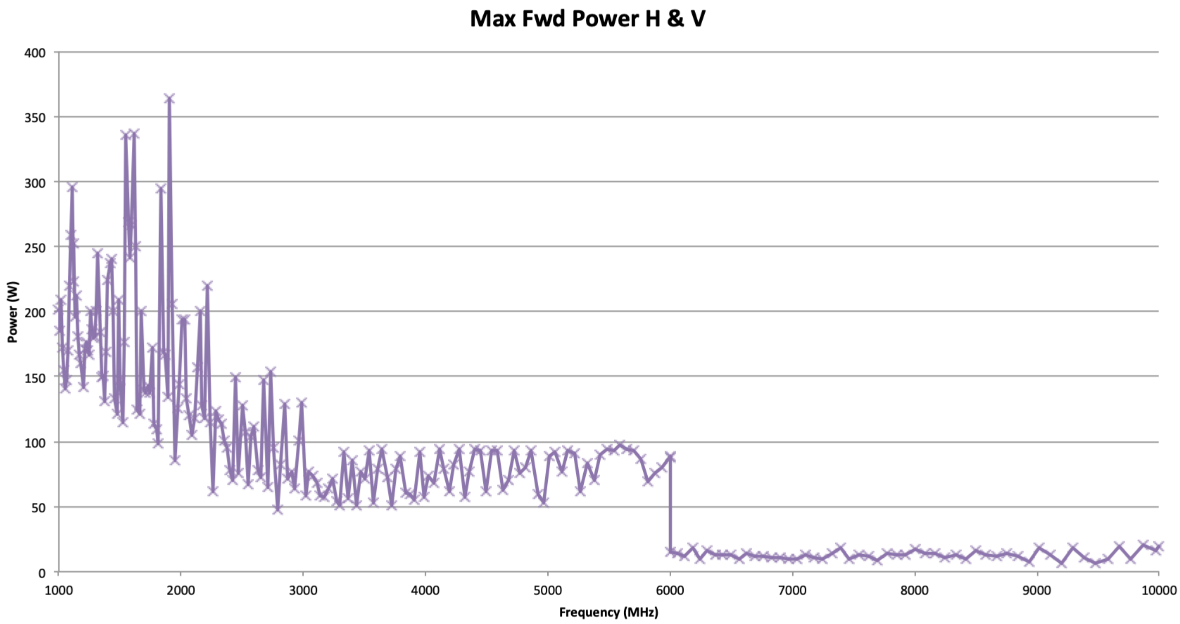


Figure 105: Forward power for 4,30 m 15-degree 1,0 x 1,0 m UFA

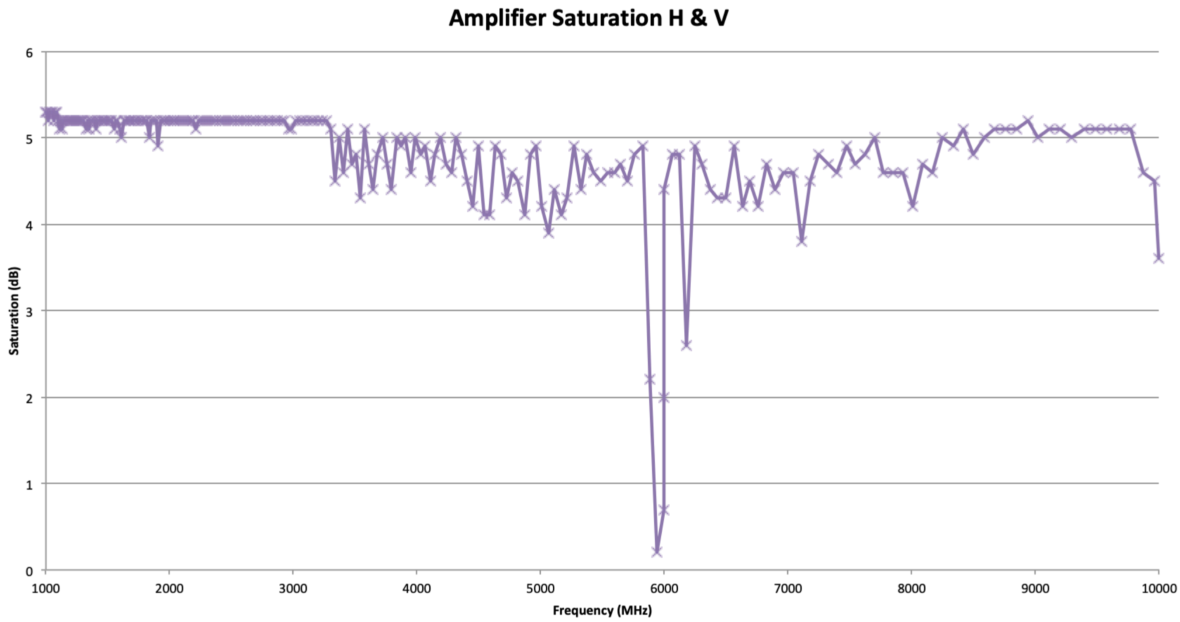


Figure 106: Amplifier saturation for 4,30 m 15-degree 1,0 x 1,0 m UFA

7.10 Appendix 10 - List of figures

7.11 Appendix 11 - List of tables

7.12 Appendix 12 - Possible cable choices 50 Ohm

Cable 1 – Black ≈2m

Leoni L45466-B14-C86

No datasheet available

Cable 2 – Dark blue – 2198235 Datasheet ≈1m

Suhner Sucoflex 104E

Frequency	<26,5 GHz
Power handling <10 GHz	200W
Power handling <6 GHz	230W
Attenuation @10 GHz	-0,8 dB/m

Cable 3 – Dark blue – Sucoflex 104 datasheet ≈50cm

Suhner Sucoflex 104PE

Frequency	<26,5 GHz
Power handling <10 GHz	50W
Power handling <6 GHz	60W
Attenuation @10 GHz	-1,15 dB/m

Cable 4 – Light blue – Hubert Suhner Datasheet ≈1m

Suhner S 04272 B

Frequency	<18 GHz
Power handling <10 GHz	38W
Power handling <6 GHz	50W
Attenuation @10 GHz	-1,13 dB/m

2x Cable 5 – Light blue – Sucoflex 104 datasheet ≈60cm

Sucoflex 104

Frequency	<26,5 GHz
Power handling <10 GHz	300W
Power handling <6 GHz	350W
Attenuation @10 GHz	-0,75dB/m

Cable 6 – Dark blue – Sucoflex 104 datablad ≈40cm

Suhner Sucoflex 104PEA

Frequency	<26,5 GHz
Power handling <10 GHz	50W
Power handling <6 GHz	60W
Attenuation @10 GHz	-1,15 dB/m

2x Cable 7 – Light green – ≈50cm

harbour industries 27478 LL142

Frequency	<18 GHz
Power handling <10 GHz	50W
Power handling <6 GHz	60W
Attenuation @10 GHz	-1,15 dB/m

7.13 Appendix 13 - Install of Loan Amplifier for 6 – 10 GHz

Hardware install

The old amplifier was placed in the rack with all cabling connected in the rear, Power, RF-OUT, Signal-in, RS232 interlock-control, remote ethernet-control, Monitor-fwd & Monitor-rev. However, the new loan amplifier has the control connections at the back and the RF-connections on the front, which causes a problem when trying to fit the existing cabling in EMC Rack 2. This caused the loan amplifier to be placed on top of the rack, backwards, secured through the handles with zip-ties. The control cabling was luckily long enough to fit, however the RF-cabling did not reach the connectors on the PA and they had different connectors. This was solved with four connectors N to SMA 90 degree bends, which adapted the right connectors and length of all RF-connections. Luckily, using these connectors did not bring unwanted VSWR or power loss to the setup, which an excess of adapters run a higher risk of doing.

Software install

Since both amplifiers were from the same manufacturer Bonn, the previously installed software in EMC32 was also sufficient for controlling the loan amplifier. However some differences had to be made to accommodate for the loan amplifier. Those were;

Network Connection

Setting the correct IP-address is needed for EMC32 to find and communicate with the PA. This process was tedious since changing its IP-address includes finding its current one, remote accessing the PA from the computer and changing it there. Normally a PA comes with the factory IP-address that is stated in the manual, however with this loan amplifier, previous users had set some other unknown IP-address. Finding the current IP-address of the amplifier was not easy, especially since it was not stated how to do so in the manual. The Rhode & Schwarz phone-support did not know how to do it without having to contact Bonn first. Pressing the buttons on the front of the amplifier gave no results and trying to use programs like Wireshark to ”sniff” the IP gave no results as well. After some hours and copious amounts of tries later, it was found in the menu that was accidentally entered by pressing one of the front buttons for an extensive amount of time.

Power Setting

The old amplifier had 50 W output power and this loan amplifier has 20 W, the setting for max power in EMC32 needs to be reduced for the signal generator not to overdrive the amplifier. 20 W is converted to 43 dB using equation (7) and we plug in 43 dB in EMC32 Hardware setup for the amplifier shown in Figure 107 below.

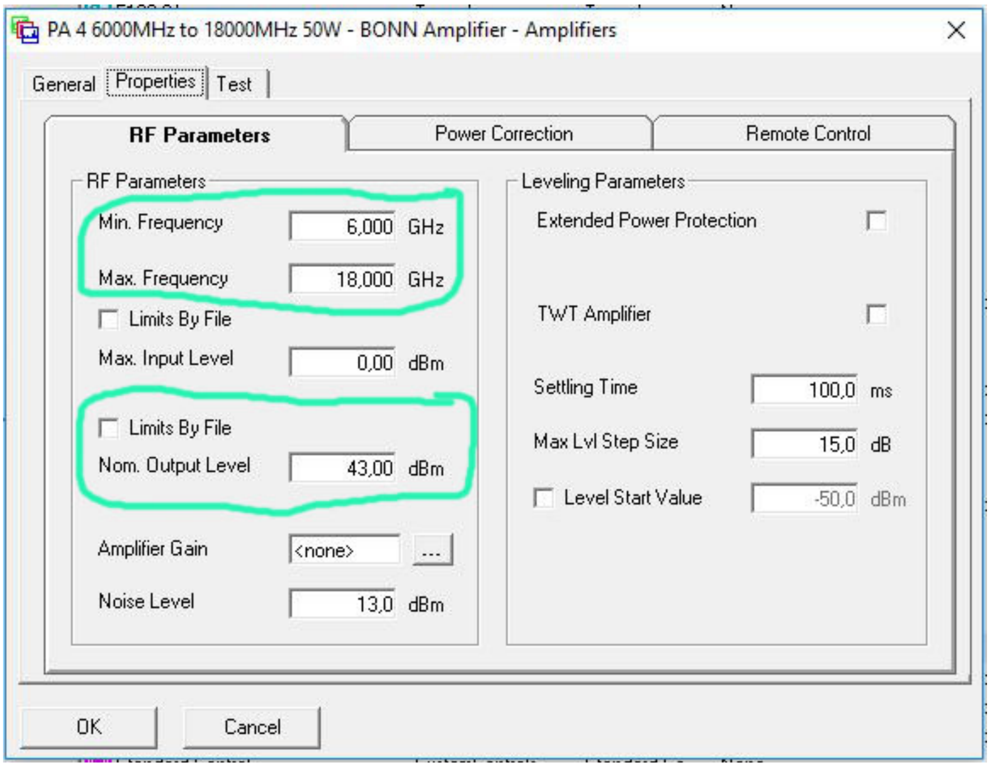
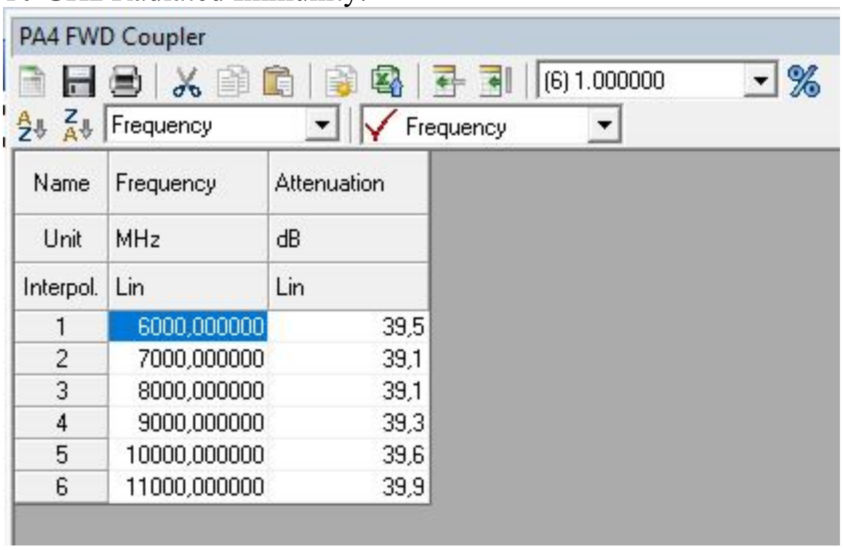


Figure 107: Power amplifier hardware setup properties

Monitor Dampening Level

The monitors for forward and reflected power in the rack take values from the amplifiers two RF-monitor ports on the front of the PA. These monitoring outputs from the PA have built in attenuation to not harm the power monitors. This attenuation is plugged in to EMC32 as shown in Figure 108 below so it can calculate and display the forward and reverse power. It is stated to be -40dB, which has been factory measured and tabulated in the manual with the real world values. These were entered in a correction table and put in to the hardware setup of 1-10 GHz Radiated Immunity.



Name	Frequency	Attenuation
Unit	MHz	dB
Interpol.	Lin	Lin
1	6000,000000	39,5
2	7000,000000	39,1
3	8000,000000	39,1
4	9000,000000	39,3
5	10000,000000	39,6
6	11000,000000	39,9

Figure 108: Correction table for amplifier monitor level

Band Select

The old amplifier was a tube amplifier with broader bandwidth than this new loan amplifier, which is solid state (Isacsson, 2020). Thus its entire bandwidth is covered using two different internal units, ”Band 1” and ”Band 2” reaching from 1-6 and 6-18 GHz. For our purpose, Band 2 has to be selected. This can be done on the amplifier itself by pressing a button on the front, or by remote controlling it. For our use, and to make sure that everything is correct set when it switches from ”local” to ”remote” control, the band is changed remotely. This is done by entering the IP-address in the web-browser, changing control focus to ”Remote” and pressing ”Band up” so that the ”Band” states number two, shown in Figure 109 below.

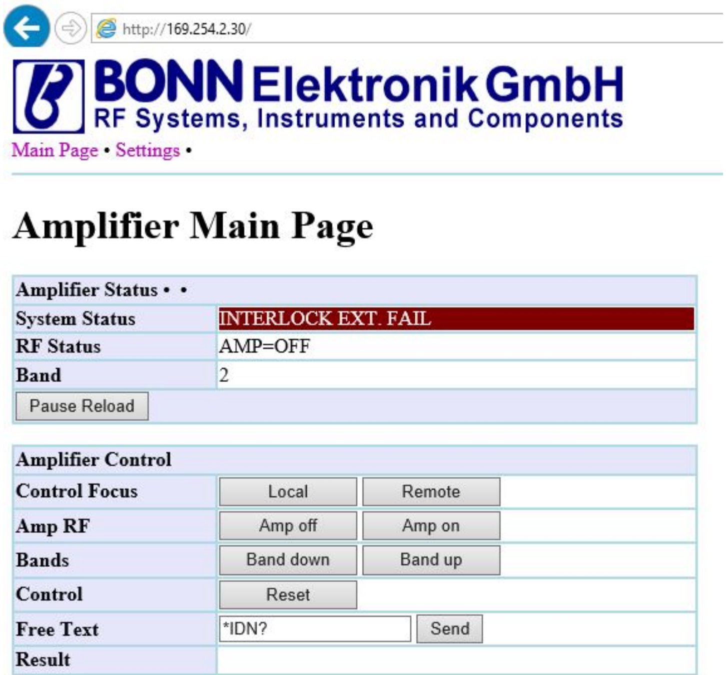


Figure 109: Amplifier Ethernet remote control