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Evaluation of Random-LOS Measurement Setup at Volvo Cars

Master's thesis in Wireless Photonics and Space Engineering

SIMON SVENSSON

Department of Signals and Systems
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Supervisors:	Amir Majidzadeh, Volvo Car Corporation
	Per-Simon Kildal, Department of Signals and Systems
	Andrés Alayón Glazunov, Department of Signals and Systems
Examiner:	Per-Simon Kildal, Department of Signals and Systems

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Department of Signals and Systems
Division of Antenna Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Random-LOS measurement setup at Volvo Cars. Measuring performance of LTE antennas of a XC90.
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Abstract

Cars are equipped with an increasing amount of wireless systems and in the near future autonomous cars will drive around in the cities and on the highways. The antennas and transceivers of these cars will have to be well tested to secure the wireless connection to the cars. To test these cars, two edge environments have been defined. The Rich Isotropic Multipath and the Random Line-of-Sight. This thesis explores the possibility of performing Random Line-of-Sight measurements at Volvo Car Corporations unshielded open range for antenna measurements. Passive and active measurement setups were built to evaluate the measurement range and the method. The active measurements are based on throughput measurements. The measurements are also compared to similar measurements performed in anechoic chambers.

The second part of the thesis is to evaluate the method by measuring on different setups and perform ”proof-of-concept” measurements. In this thesis SISO measurements and SIMO measurements are compared as well as the placement of an antenna inside the car or mounted on the roof of the car.

It is concluded that Random Line-of-Sight measurements can be performed at the Volvo open range, but multipath effects increase at the higher end of the frequency band tested. The Volvo open range is unshielded and there is a lot of interference present. The combination of multipath effects and interference limits the frequencies that can be tested and limits how well performance of different bands can be compared. The method can measure a performance difference between SISO and SIMO measurement, and measure a 4.5 dB improved performance when using SIMO. Because of limitations of the setup the effects of body of the car could not be well measured, it is approximated from the measurement that the body of the car cause 7.5 dB attenuation when placing an antenna inside the car compared to mounted on the roof.

Keywords: Random-LOS, Automotive Measurements, OTA-testing, open range, anechoic chamber.

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Contents

1

Introduction

A modern car is equipped with a lot more communication equipment and antennas than a few yeas ago. Previously cars have been equipped with broadcast receivers such as AM and FM radio. A modern car is equipped with cellular technologies such as 3G and 4G for telephony and mobile internet access, bluetooth to communicate with smartphones and other devices, several WiFi networks, TV, DAB, satellite radio, and GNSS. The amount of wireless systems used in cars will continue to increase in the near future. In 2014 the EU decided that all new cars from April 2018 has to be equipped with eCall[1]. eCall is a system adopted by EU to decrease response time for emergency services in case of an accident. In case of an accident the eCall system automatically informs the emergency services via the cellular network about the accident including the GPS coordinates of the car and the status of the car such as airbags and direction of travel before the accident.

The IEEE standard 802.11p which was superseded by IEEE1609 standard is a standard for Wireless Access in Vehicular Environments or more commonly referred to as Car-to-Car(C2C), Car-to-Anything(C2X), Vehicle-to-Infrastructure(V2I) or Vehicle-to-Anything(V2X) communication[2]. It is intended primarily for warnings to increase safety. It utilizes frequencies in the ITS band above WiFi, 5.85-5.95 GHz. V2X systems will be implemented in the near future.

In the future with autonomous driving cars the need for reliable wireless communication will increase even more and the need for effective testing of those systems and antennas will be critical.

In the automotive industry, traditionally system tests are performed through field trials.

1.1 Background

Classical antenna design and measurements are centered on designing an antenna with main beam of a specific shape, requirements of the side lobes and bandwidth of the antenna. This is very useful for applications such as radars, point-to-point communication links, and radio astronomy. You are interested in transmitting and receiving in only one direction and in particular when interference from other sources is undesired. Your intended target is in Line-of-Sight(LOS). In the ideal case there exists no reflections when using these kinds of system, only pure Line-of-Sight. These systems are commonly tested in an anechoic chamber which absorbs all reflections as a representation of the ideal edge case.

With hand held mobile devices in urban areas it is uncommon to have Line-of-

Sight to the device you are trying to communicate with. Common systems are mobile phones and laptops which connect to basestation of the cellular network or WiFi networks. Phones are expected to work indoors and laptops are expected to achieve WiFi connection without pointing them at WiFi access-points. The systems rely on the reflections to function, by reflections on scatters in the environment, the signal can travel multiple paths from the transmitter to the receiver. As an ideal edge case these systems are interesting to test in an environment that is the complete opposite to the pure Line-of-Sight case. The Rich Isotropic MultiPath(RIMP) is an ideal edge environment, where the waves arrive isotropically from all directions[3]. The RIMP environment can be simulated in a multi probe setup or in a reverberation chamber. The reverberation chamber is in essence a metal box which reflects the waves well, the Line-of-Sight component is blocked and the modes in the chamber are stirred by moving plates in the chamber to achieve a RIMP environment.

Considering a car on a highway, both the traditional LOS and the RIMP ideal edge case are not very representative for system performance. In a highway situation a car has a strong LOS component to the basestation, however since the antenna on the car is not actively pointed towards the basestation, the concept of a main beam is often not relevant. A new ideal edge case has been suggested for automotive application, Random Line-of-Sight,(Random LOS or RLOS). With active measurement and using statical concepts similar to those used for a RIMP environment, antennas for this application can easily be compared. With the edge case of RIMP and Random-LOS it is believed that the performance of antennas for automotive applications can be well tested[4].

1.1.1 Over The Air Testing

Over-The-Air(OTA) testing or active measurements is a concept of measuring on a device and its antenna. Classically you have a closed loop, you connect a cable to the antenna you want to test and one cable to a known antenna and you connect both antennas to a network analyzer and measure how much power you receive with the antenna you are testing if you transmit on the known antenna. In OTA testing you connect the antenna you want to test to the intended device and use a communication tester to communicate with the device wirelessly, over the air, and measure the throughput between the communication tester and the device under test. To test a device with an integrated antenna such as a phone, classical measurements are impossible without adding a test port to the phone.

OTA testing use the entire system of the device. In modern systems, receivers and transmitters use more than one antenna for decreased singal to noise ratio or increased throughput, from respectively diversity or multiple-inputs and multiple-outputs(MIMO). Performance gain from diversity and MIMO can only be measured with OTA testing since the signal processing is necessary and affects the performance. OTA testing is a system test. Today 2X2 MIMO is used, however larger MIMO arrays will be used in the future and have been demonstrated[5].

Table 1.1: Relative appearance of the RIMP and RLOS edge case in real life[4].

Case	RIMP	Random-RLOS
Smart Phones	90%	10%
Laptops	80%	20%
Micro base station	60%	40%
M2M	50%	50%
Automotive	20%	80%

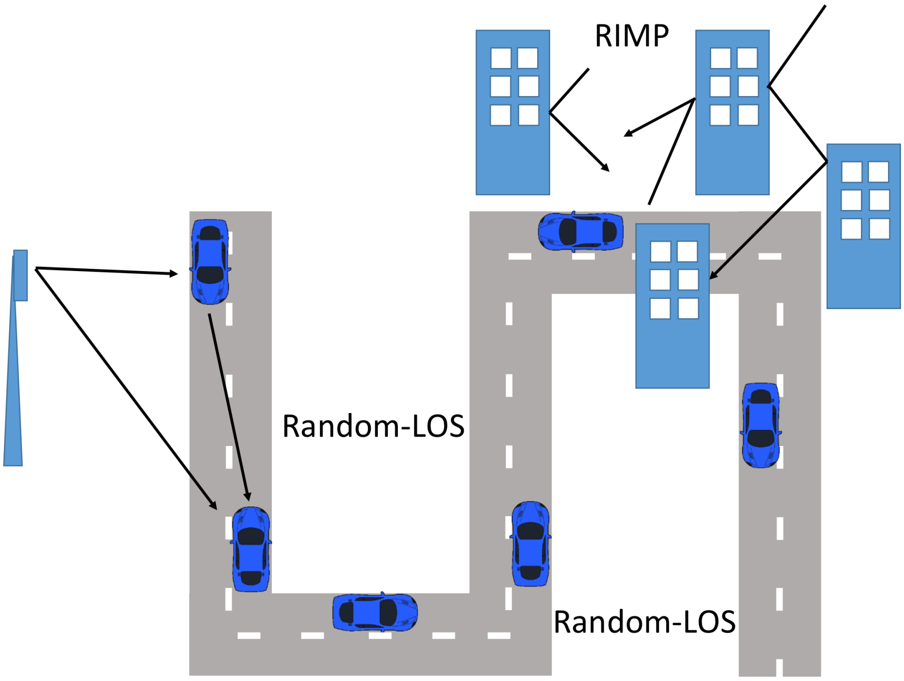


Figure 1.1: Illustration of the change between RLOS or RIMP edge case relation to real life use[10].

1.1.2 RIMP or RLOS

With the introduction of the Random LOS environment it was hypothesized[4] that real life performance can be tested by using the two edge cases RLOS and RIMP. Further, for different applications the relative importance of the RIMP and RLOS cases are hypothesized to be as shown in table 1.1[4]. The RIMP edge case is well known and can for example be measured in the reverberation chamber[6][7], with a multi probe setup[8] or the two stage OTA test method[9].

For a a hand held device the Random LOS will be a 3D-random, since they are expected to work in any orientation. For the automotive case it becomes closer to a 2D-random case. The general idea is that a car experience a RLOS like environment at a highway but more RIMP like environment in urban areas, see figure 1.1.

1.2 Purpose

The aim of the thesis is to build a Random Line-of-Sight measurement setup at Volvo Car Corporation's existing antenna measurement range to evaluate the method and to evaluate the measurement range for Random Line-of-Sight measurements. The setup should measure LTE(Long-Term Evolution), commonly marketed as 4G LTE, performance. As part of the evaluation of the method, if possible, it should be tested for evaluating the effects of the body of the car when using an antenna inside the car compared to an antenna mounted on the roof. As part of the evaluation of the measurement range, measurements should if possible be compared with measurements is SPs semi-anechoic chamber.

2

Theory

2.1 Threshold Receiver and Probability of Detection

A digital RF transceiver used in modern communications systems can be approximated as a threshold receiver. If a cable is connected between a real transmitter and a receiver, the conducted case, and the output power of the transmitter is swept, a very steep throughput(TPUT) curve can be measured. To model the system a threshold can be used, see (2.1)[11][12], where P is the received power.

$$\mathrm{TPUT}_{\mathrm{conducted}}(P) = \mathrm{TPUT}_{\max} \begin{cases} 1 & \text{if } P > P_{\mathrm{Threshold}} \\ 0 & \text{if } P < P_{\mathrm{Threshold}} \end{cases} \tag{2.1}$$

In a dynamic environment the input power will vary depending on the channel. The relative average throughput is equal to the number of observation of instantaneous power above relative to below the threshold. The average relative throughput is equal to the Probability of Detection(PoD).

To relate the PoD to the radiation pattern of an antenna, the relationship of the average received power and the PoD is needed. The radiation pattern is related to the probability of outage which is the complement of the PoD, see (2.2)[13], where P_{th} is the threshold, P_{av} is the average received power, the CDF is the cumulative distribution function of the channel.

$$\mathrm{TPUT}(P_{av}) = \mathrm{TPUT}_{\max}\mathrm{PoD}(P_{av}/P_{th}) = \mathrm{TPUT}_{\max}(1 - \mathrm{CDF}(P_{th}/P_{av})) \tag{2.2}$$

From a measurement, two ways to calculate the PoD from a power and angle sweep are used in this thesis. From ideal measurements the two methods yield identical results but they have different requirements on the measurement setup. If the angle is fixed in a RLOS measurement during each power sweep and the angle is changed after each power sweep the threshold level is given by (2.3).

$$P_{\mathrm{Threshold}} = \min(P) \text{ when } \mathrm{TPUT}(P) \geq 0.5 \cdot \mathrm{TPUT}_{\max} \tag{2.3}$$

The PoD is after establishing the threshold for all the stationary states given by (2.4).

$$\mathrm{PoD}(P) = \mathrm{CDF}(P_{\mathrm{Threshold}}) \tag{2.4}$$

Another way of calculating the PoD is by having the power sweep in the outer loop calculating the average throughput of all measured states for each power level, see (2.5), where n are the measured states. The relative average throughput is related to the PoD according to (2.5).

$$\mathrm{PoD}(P) = \frac{1}{N}\sum_{n=1}^{N}\frac{\mathrm{TPUT}_n(P)}{\mathrm{TPUT}_{\mathrm{max}}} \tag{2.5}$$

2.2 Isotropic Reference

In Random LOS measurement it is still generally undecided what should be used as reference and how. In this report the reference used is an isotropic antenna. The Scientific Atlanta Standard Gain Horn with a known absolute gain is used to measure the free space path loss with a VNA. A throughput measurement with the standard gain horn gives a threshold which is used to reference the PoD curves to the threshold of an isotropic antenna, see (2.6). This means that a measurement with an isotropic antenna would result in a step in the PoD curve at 0 dB and a worse antenna would result in a positive value.

$$P = P_{\mathrm{AUT}}\frac{G_{\mathrm{Reference}}}{P_{\mathrm{Reference}}} \tag{2.6}$$

In this thesis, at instances were the absolute value is not of interest the results are displayed relative to the power at the AUT. At some instances the data sets will, for clarity, be offset from each other and will only internally be correct, for those plots the reference is intentionally dropped.

2.3 Multiport Antennas

An antenna setup with more than one active element is called a multiport antenna. In practice this could be two or more antennas connected to the same receiver or two or more antenna elements in the same module, such as an array antenna. With a transmit antenna with N_t ports and a receiver with N_r ports there are $N_t \times N_r$ channels. The channel is the S-parameter between the transmitting and receiving port, including the antennas.

2.3.1 SISO - Single Input, Singe Output

The simplest case for a communication link is the Single Input, Singe Output(SISO) mode. It uses one antenna for the transmitter and one for the receiver.

2.3.2 SIMO - Single Input, Multiple Output

Single Input, Multiple Output(SIMO) uses two or more antennas on the receiver. The antennas need to be separated in space, radiation pattern or polarization. The antennas will experience different channels and the signal is combined to minimize the effects of fading. Common algorithms for diversity are Selection Combining(SC) and Maximum Ratio Combining(MRC)[11].

The Selection Combining is a very simple algorithm, it chooses the receiving port with the best SNR and uses only that port. The other ports are not used.

Maximum Ratio Combining is based on an estimation of the channel. The channel is estimated with a pilot signal that is transmitted before the data. The summation of the received signal is weighted by the complex conjugate of the estimated channel for each port, see (2.7) where C is the modulated signal and C_{Opt} received modulated signal optimally combined with MRC and h is the channel and h' is the estimation of the channel. Resulting a conjugate match. A conjugate match ensures maximum power is delivered to the load[11].

$$C_{Opt} = \sum_i C(t) h_i \cdot h_i'^* \tag{2.7}$$

The gain from using more than one antenna in this manner is called diversity gain.

2.3.3 MIMO - Multiple Input, Multiple Output

Multiple Input, Multiple Output(MIMO) use two or more antennas for both the transmitter and receiver. A MIMO system can be modelled as in (2.8) where $\mathbf{x}$ is the transmitted symbols vector, $\mathbf{y}$ the received symbols vector and $\mathbf{H}$ is the channel matrix. Equation (2.9) is an example for a 2×2 MIMO system(2 transmitting and 2 receiving antennas). If there are two or more orthogonal channels between the transmitter and receiver, the channel matrix has a rank larger than 1, more than one bitstream can be transmitted. Having two bitstreams instead of one doubles the throughput of the system[11].

$$\mathbf{y} = \mathbf{H}\mathbf{x} + n \tag{2.8}$$

$$\mathbf{H} = \begin{Bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{Bmatrix} \tag{2.9}$$

In a ideal Line-of-Sight system the only way to get two orthogonal channels is by polarization diversity.

2.3.4 LTE transmission modes

In LTE release 12 there are 10 Transmisssion Modes(TM) for the downlink[14][15]. These 10 modes are described in table 2.1. For this thesis mode 1 and 3 are of interest. Since the transmission mode describe the transmitter but not the receiver TM 1 is used for both SISO and SIMO transmissions. Transmission mode 2, transmit diversity uses more than one antenna at the basestation independent of the number of antennas at the receiver and use Alamouti Coding to get a diversity gain. Transmission mode 3, open loop MIMO, is used for MIMO measurements since we are interested to study the change of throughput for different channels. In TM 4, closed loop, the basestation will compensate, based on feedback, for the channel. Since

Table 2.1: The 10 different transmission modes(TM) described in LTE release 12 for the downlink[14][15].

TM	Description	Comments
1	Single transmit antenna	Used for SISO and SIMO
2	Transmit Diversity	2 or 4 antennas
3	Open Loop MIMO	2 or 4 antennas
4	Closed Loop MIMO	2 or 4 antennas
5	Multi User MIMO	2 or 4 antennas
6	Closed Loop Spacial MIMO using a single transmission layer	2 or 4 antennas
7	Beamforming	1 virtual antenna port, depends on implimitation
8	Dual layer beamforming	2 virtual ports
9	8 layer transmission	Up to 8 layers
10	8 layer transmission	Up to 8 layers

TM 4 is dependent of the performance of the basestations performance it will not be used for this thesis.

2.3.5 Self Grounded Bowtie Antenna

As transmitter antenna when doing active measurements in RLOS, a dual polarized antenna is used to achieve orthogonal channels. The ultra wide band self grounded bowtie antenna using differential excitation is used[16]. It is a four port bowtie antenna. The entire antenna is made out of one piece of sheet metal. The petals are bent towards the center and soldered to the four ports, the base of the antenna is grounded[16], figure 2.1.

For use as a 2 port dual polarized antenna opposing petals are fed differentially with a 180° hybrid. With hybrids the bowtie antenna has a gain of about 3 dBi at 1.5-3 GHz[16]. When used for a single polarization the unused port at the unused hybrid has to be terminated.

2.3.6 Shark Fin Antenna

The multi port antennas which is mounted on the roof top of Volvo cars are generally called Shark Fin Antennas, it is internally officially called Multi band Antenna Module(MAM). The Shark Fin antenna is equipped with several antennas for different applications. The Shark Fin has two vertically polarized LTE antenna elements and the roof acts as a ground plane for the antennas. For all measurements where the Shark Fin has been mounted on a car, the Shark Fin has been mounted on a second generation XC90 with sunroof. The Shark Fin is mounted under a protecting radome, see figure 2.2.

Since the car roof acts as a ground plane the antennas can not be horizontally polarized. Therefore, in a pure line-of-sight environment if the Shark Fin antenna behaves ideally as a monopole it can not be used for MIMO.

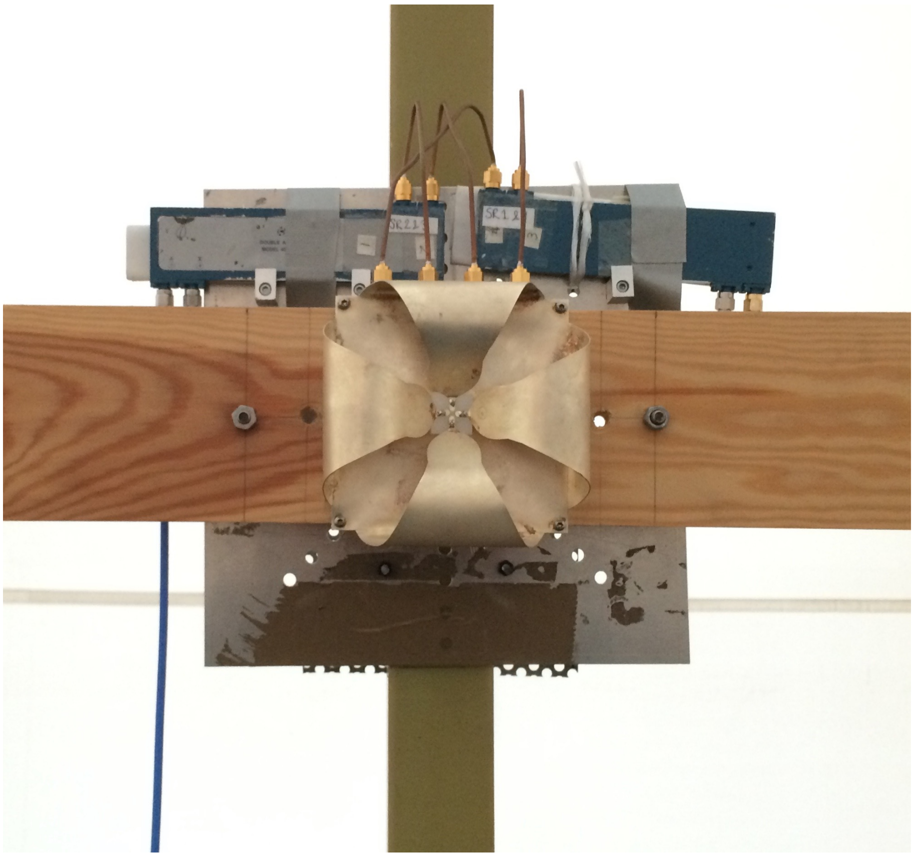


Figure 2.1: The Self Grounded Bowtie antenna mounted with hybrids.

(a) Shark Fin on a ground plane

(b) Roof

Figure 2.2: The Shark Fin with radome, close up with marked position of the LTE 1 and LTE 2 antenna

2.4 RIMP and RLOS for Chamber Evaluation

Rich Isotropic MultiPath(RIMP) is the ideal edge case corresponding to an environment with many scatters. Multipath refers to that the signal takes multiple paths from the transmitter to the receiver. Isotropic refers to that the Angle of Arraival(AoA) of the wave towards the receiver is isotropically distributed in the unity sphere around the receiver. Rich refer to that there are many waves[11].

If there are no LOS component the received complex signal in RIMP will be normally distributed, complex gaussian. The signal magnitude will thus be Rayleigh distributed, (2.10).

$$\mathrm{CDF}_{\mathrm{Rayleigh}} = 1 - e^{-x^2/2\sigma^2} \tag{2.10}$$

With a omnidirectional antenna in Random Line-of-Sight(RLOS) environment the PoD will ideally be a step. By comparing the PoD from a measurement with a good omnidirectional antenna in an unknown environment with a Rayleigh distribution and a step, the quality of a chamber for Line-of-Sight measurements can be evaluated.

3

Method

The measurements performed in this thesis are of two general types, passive and active. In the passive measurement only the antenna can be tested. The Antenna Under Test(AUT) is connected directly to a Vector Network Analyzer(VNA) and the transceiver of the Device Under Test(DUT) is not part of the system. Only the passive antenna is measured. In the active measurements the AUT is connected to the DUT and a Over-The-Air(OTA) connection between the the DUT and the measurement equipment is used to measure the performance of the system. Diversity and MIMO effects can be tested in the active measurement but not in the passive measurement. The measurements that were performed with a car was done on the second generation XC90, with sunroof. They were made on either DWU868 or DUG662 depending on which measurement series they were a part on. The differences between the two cars are in the interior and engine, which should not effect the measurements.

3.1 Passive Measurements

The classical antenna measurement setup utilizes an anechoic chamber and a Vector Network Analyzer. It is used to measure the radiation pattern, qualities such as the gain, directivity, beam width and side lobe levels can be evaluated. In a reverberation chamber passive measurements include radiation efficiency.

3.1.1 Radiation Pattern Measurement

An antenna's radiation pattern is ideally measured in an anechoic chamber. The walls of an anechoic chamber is lined with absorbers. In an ideal anechoic chamber the walls absorb all microwave radiation. The aim is to measure in a pure Line-of-Sight environment, without any reflections.

The AUT is placed on a stand on a turntable in one end of the chamber, in the other end a chamber antenna is placed, see figure 3.1. The chamber antenna and the AUT are connected to a VNA. The chamber antenna is normally connected to port 1 of the VNA and is sometimes also called the transmitter antenna and the AUT is connected to port 2 of the VNA and is sometimes referred to as the receiver antenna. The VNA is used to measure S_{21} and the turntable is turned to measure S_{21} for the entire plane. By turning both the chamber and antenna under test 90° around their own axis the other plane can be measured, as a result both the E-plane and H-plane of the AUT can be measured.

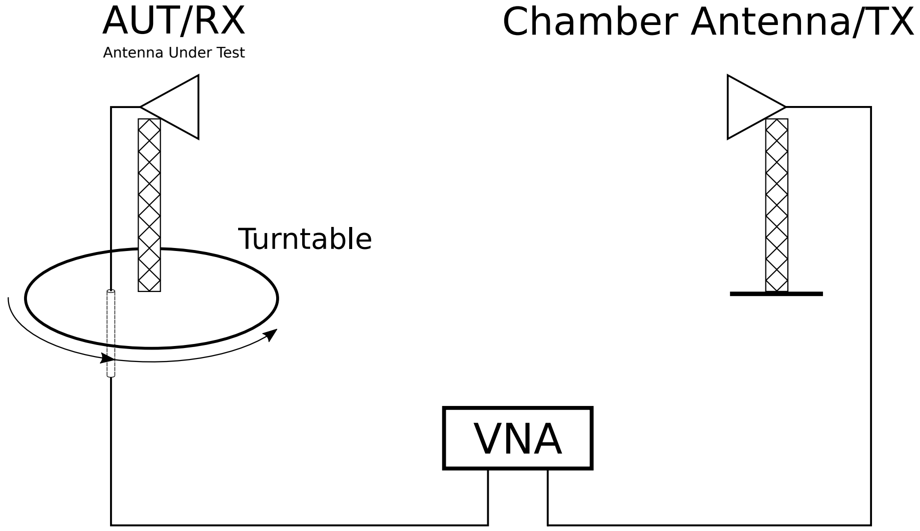


Figure 3.1: The antenna under test is placed on a turntabel and the chamber antenna is placed on the opposite side of the anechoic chamber.

To be able to measure absolute gain the measurements have to be compensated for the free space path loss and the gain of the chamber antenna. The measurements have to be normalized with measurements of a reference antenna with known gain.

3.1.2 Passive Measurement Setup at Volvo

The antenna measurement range at Volvo is not an anechoic chamber, it is an open range measurement site. The range is unshielded and without any absorbers. The site is covered by a tent with wooden beams for weather protection and minimal amount of reflections, see figure 3.2. The distance between the chamber antenna and center of the turntable is 11.5 m.

The transmit antenna at Volvo is mounted on a movable stand. Thus its position, polarization and angle to the receiver will be slightly altered if the antenna is moved between measurements. The turntable has a beam mounted to help with aligning the front wheels of the car, however naturally the turntable does not have a fixed fixture for measuring on other kinds of antennas and they are subject to the same issues as the transmitter. The antennas are aligned by markings on the ground, lasers for alignment, distance measurements and spirit levels.

The turntable at Volvo can not be controlled remotely, its angular velocity can manually be set at an arbitrary scale. For each degree the turntable moves it transmits a pulse on a coaxial cable. The network analyzer used at the Volvo site for passive antenna measurements is a Agilent 8753ES, S-network analyzer which can be controlled over GPIB. The signal was amplified using a Mini-Circuits ZHL-42W+ amplifier to compensate for the attenuation of the long cables from the control room to the tent. As part of this thesis a suite of tools for controlling the equipment, collecting the data and displaying the data were designed in LabView.

Since the turntable can not be remotely controlled it is constantly rotated during the measurements. Normally one would have done a measurement for a single fixe angle and then move. This was not possible here. For each pulse received(once every

(a) Tent (b) Inside

Figure 3.2: The open range at Volvo covered by a tent. The turntable has radius of 198 cm and the distance from the chamber antenna to the center of the turntable is 11.5 m

angle), a single sweep is performed. This means that the sweep time needs to be less than the time it takes for the turntable to move 1 degree.

For all passive measurements a Scientific Atlanta Standard Gain Horn 11-1.7 was used as reference. It is calibrated for 1.7-2.6 GHz. In preparation for the active measurements two different transmit antennas were used, a Schwarzbeck USLP 9142 log periodic antenna and a self grounded bowtie antenna[16] with the unused element terminated.

The distance between the transmit antenna and the center of the turntable is 11.5 m. The turntable is too small to place the antenna mounted on the car in the center of the turntable, however the distance lowers the effects from the antennas offset from the center of the main beam of the transmitter antenna. At ±90°, where 0° is when the font of the car is pointed at the chamber antenna, the distance from the center is about 1.5 m, depending on the car model. For the XC90 the offset is approximately 160 cm.

3.1.2.1 Measurements with Omnidirectional Antenna

To evaluate the site in regards to reflections, passive measurements with a omnidirectional antenna were performed. The antenna measured on was a Bluetest Discone Antenna 0.7-4.2 GHz and as chamber antenna, transmit antenna, the Log Periodic antenna was used. The discone antenna was placed in the center of the turntable and offset 160 cm. To investigate the impact of ground reflections the measurements were performed with and without absorbers placed on the ground between the chamber antenna and the omnidirectional receiver antenna, see figure 3.3. The measurements were performed in the frequency range of 1.7-2.6 GHz, limited to the bandwidth of the reference standard gain horn antenna. The height of both antennas was 180 cm.

3.1.2.2 Spectrum Analyzer Measurement

The spectrum was measured by using the omnidirectional discone antenna, mounted on the same stand as previously and in the center of the turntable, and an Agilent

(a) Setup with Absorbers

(b) Discone Antenna

Figure 3.3: The omnidirectional Discone antenna setup for passive measurements with absorbers. The Log Periodic antenna is used as Chamber antenna.

N9010A EXA Signal Analyzer. It was measured in max hold mode for the 1.7-2.6 GHz frequency band.

3.1.2.3 Measurements with Shark Fin Antenna on a stand

Initial measurements on the shark fin were performed with the Shark Fin antenna with a ground plane placed on a stand . The measurements were performed with two different ground planes, see figure 3.4.

The two elements of the Shark Fin antenna were measured as embedded elements. The antenna element under test was connected to the VNA and the other element was terminated by a 50 Ω load. The antenna has to be fed with 12 VDC to activate an internal RF switch to connect the LTE 2 antenna to its port, the antenna is fed during all measurements. The radiation pattern for both ports and both ground planes were measured.

3.1.2.4 Measurements with Shark Fin Antenna on XC90

Radiation pattern measurement of a Shark Fin mounted on a XC90 with Sun Roof was measured with both the Log Periodic and the Bowtie as Chamber antennas. The radiation patterns were measured for both LTE antenna ports of the Shark Fin antenna in the same manner as when they were mounted on the stands, see figure 3.5.

3.2 Active Measurements

The active measurements are system measurements. The Antenna Under Test(AUT) is connected to the Device Under Test(DUT). Depending on what is intended to measure the device could be a reference device or the final product. During this

(a) Square

(b) Round

Figure 3.4: The two used ground plane. The square ground plane, figure 3.4a, is 30 × 30 cm, and the round ground plane, figure 3.4b, is 50 cm in diameter.

Figure 3.5: Radiation pattern measurement setup for measuring of Shark Fin mounted on XC90, DWU868.

(a) Front (b) Back (c) Inside

Figure 3.6: The CMW-Z10 shielded box used. 3.6a Shows the front with the USB input, 3.6b shows the back with the RF connectors and 3.6c shows the inside with the dongle connected.

thesis a LTE dongle from Huawei(E398) has been used, it supports LTE Band 1,3,7 and 8. The Huawei dongle has support for LTE and MIMO and it has two external TS9 antenna ports. The dongle was placed in a Rohde & Schwarz CMW-Z10 RF Shield Box to make sure the internal antennas do not effect the measurement, see figure 3.6. The Rohde & Schwarz CMW-Z10 RF Shield Box has >80 dB attenuation for the frequencies of interest. The shielded box has a USB input used for connecting the dongle to a computer and N-connector outputs used for connecting the outputs of the dongle to the AUT.

The chamber antenna is connected to a Rohde & Schwarz CMW500 Wideband Radio Communication tester, see figure 3.8. For the active measurement the bowtie was used as chamber antenna. The CMW500 emulates a LTE basestation. The dongle is equipped with a special test SIM card intended to be used together with the CMW500. The dongle connects to the CMW500 over the air, in the same manner as it would connect to a normal basestation if it was equipped with a normal SIM card. When connected and measuring no cables connect the DUT to the CMW500, see figure 3.7. The DUT operates as it would normally and the settings associated with the basestation such as output power, modulation and frequency band and channel are controlled by the CMW500. The distance between the chamber antenna and the turntable was the same for the passive and active measurements.

The maximum output power of the CMW500 is -15 dBm, with the distance used at the Volvo measurement site between the Chamber antenna and AUT it was not enough to automatically establish connection between the CMW500 and the DUT, the dongle. For all active measurements a SISO connection was established using the conducted case, connecting a long coaxial cable between one of the extra ports of the CMW500 and one of the DUT and then transferred to SISO OTA connection using the other port of the DUT and the CMW500. The cable was then removed and the intended antenna setup was connected to the DUT depending on doing SISO or SIMO measurements.

After analyzing the results from the passive measurements band 1 channel 490 was chosen for the active measurements. Channel 490 uses 2159 MHz for its downlink and 1969 MHz for its uplink. The modulation format was fixed to 16-QAM for the downlink and QPSK for the uplink. The system bandwidth was 5 MHz. Downlink

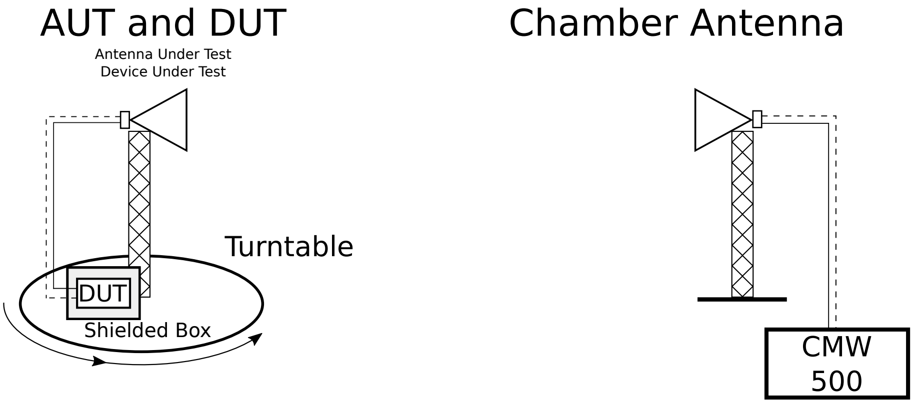


Figure 3.7: Setup for active measurements. The dotted cables are connected or not depending on antenna setup.

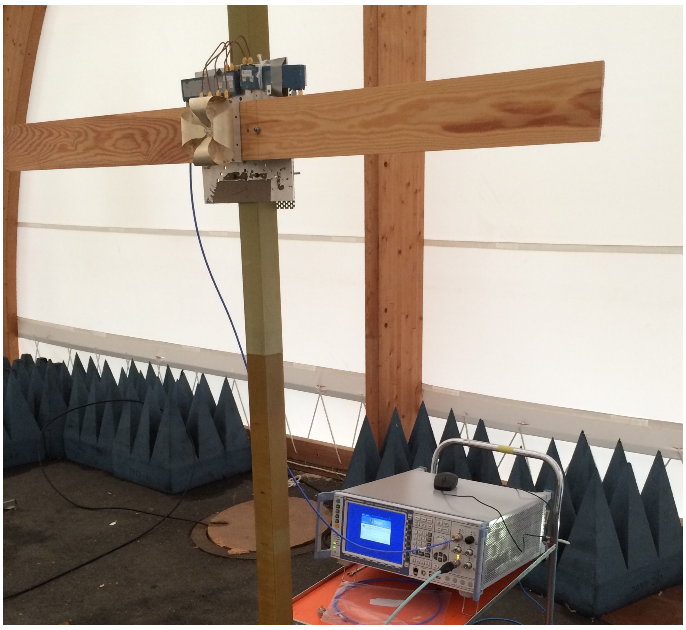


Figure 3.8: The CMW500 connected to the Bowtie antenna, ready for LTE TM1 measurement. The second connected cable is used for establishing connection and not for measurements.

throughput measurement was performed.

During the active measurements the throughput is measured while performing a power and angle sweep. This has been performed in two different ways. In this thesis they are named Continuous Mode and Stepped Mode.

3.2.1 Continuous Mode

During the Continuous Mode the AUT is continuously rotated and the power sweep is the outer loop. The turntable is continuously turned and in the similar manner as during the passive measurements, once for each degree the AUT is turned a throughput sample is measured. After a complete 360° turn is performed the power level is lowered and the next turn begins. With the Volvo setup where the turntable can not be remotely controlled, this mode of operation can be automized and is quite fast. Since the car is heavy, starting and stopping the rotation of a car takes relatively long time this method would probably save time even for setup where the turntable can be remotely controlled. The automation software for controlling the CMW500 and listening to the turntable to perform the measurements and collect data were made as a part of the thesis work.

During the measurements the speed of the turntable and the sample speed were slightly out of phase and only 330 samples were collected for a complete turn. Since lowering the output level of the CMW500 takes too long to be performed within the time it takes for the AUT to be moved 1°, the exact position of each sample is not tracked. It is only tracked that for each power level samples are taken evenly during a complete revolution and only during a single revolution.

In continuous mode the average throughput at each power level relative to the maximum throughput is used to calculate the probability of detection according to equation 2.2 and 2.5. Since the average throughput is used, knowledge of absolute angle is not needed.

3.2.2 Stepped Mode

During Stepped Mode the AUT is stationary during the measurement. The AUT is moved to a specified angle and while stationary a complete power sweep is performed. Then the AUT is moved and a new power sweep is performed. During this thesis the angle has been stepped in 10° increments and for each power level 15 samples were collected. In the ideal case all 15 samples should be identical. The stepped mode operation takes longer than the continuous mode, however when constantly monitored and controlled, worse performing antennas can be measured. It is however very labour intensive.

The probability of detection is calculated in two different manners. For both the PoDs is the CDF of the threshold values as in equation 2.4. At each stationary angle and power level either the sample with the highest throughput, equation 3.1 or the average throughput, equation 3.2, of the 15 samples is used to calculate the threshold according to equation 2.3.

$$TPUT(P) = \begin{cases} \max\limits_{n}(\mathrm{TPUT}_n(P)) & (3.1) \\ \dfrac{1}{N}\sum\limits_{n=1}^{N}\mathrm{TPUT}_n(P) & (3.2) \end{cases}$$

These are referred to as Best Sample and Average method in the rest of the thesis. With both methods the threshold is detected at the 50% level. It is assumed that interference can lower the throughput but not increase it, at instances with more than one crossing of the 50% threshold level the first one is used.

3.2.3 Measurement setups

Active measurements have been performed for several setups. The difference in performance for the different transmission modes and for different placements of the antenna as well as different antennas.

3.2.3.1 SISO

Single Input Single Output(SISO) measurements for the Shark Fin LTE 1 and LTE 2 mounted on a XC90 have been performed. During SISO measurement the unused port on the Shark Fin was terminated. SISO measurements have been performed in Stepped mode. Only vertical polarization was used from the CMW500 and Bowtie chamber antenna. The Shark Fin SISO performance for LTE 1 and LTE 2 was measured in a XC90 with sun roof with car ID DWU868.

3.2.3.2 SIMO

Single Input Multiple Outputs measurements with the Shark Fin antenna mounted on the XC90 were performed both with stepped mode and with continuous mode. During SIMO measurements both antenna ports of the Shark Fin were connected to the dongle. Only vertical polarization was used from the CMW500 and Bowtie chamber antenna. The Shark Fin SIMO performance was measured in two XC90, both with sun roof with car ID's DWU868 and DUG662.

3.2.3.3 MIMO

Multiple Inputs Multiple Outputs connection with multiple bit streams can theoretically not be established between the Shark Fin antenna and any transmit antenna in a Line-of-Sight environment. However, with enough output power it can be established since the antennas are not ideal. With the antenna mounted inside the car it would theoretically be possible to achieve MIMO connection since it would not be a pure Line-of-Sight environment. However in the setup at Volvo with the long distance between the AUT and the chamber antenna the CMW500 could not deliver enough power to achieve MIMO connection in any position of the Shark Fin antenna.

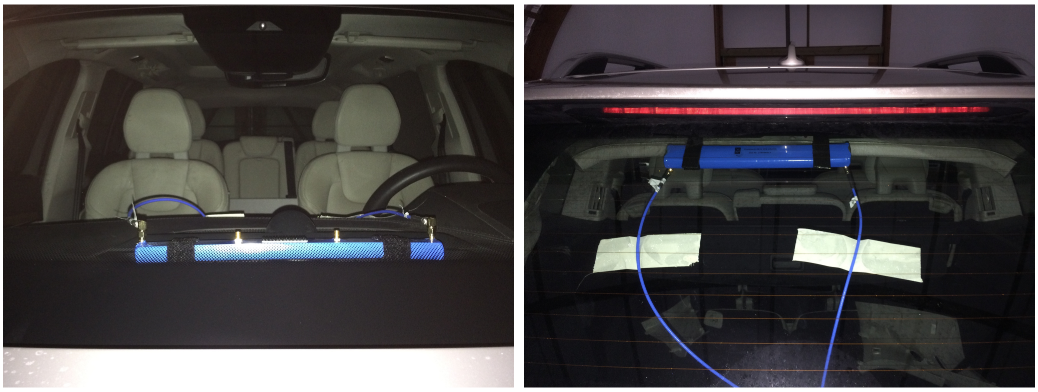
Figure 3.9: The Shark Fin mounted on the Cup Holder in a XC90.

3.2.3.4 SIMO with Shark Fin inside the car

If you want to integrate an antenna inside the car instead of on the roof or compare the performance of a phone inside the car to the cars system which use the shark fin, the effects of the body of the car is interesting. The Shark Fin was placed inside the car between the driver seat and passenger seat, on the cup holder, see figure 3.9. The Shark Fin was mounted with ground plane and its radome to as best as possible measure only the effect of changing the position and not the effects of different ground planes. At the Cup Holder position only SIMO performance was measured. The Shark Fin was measured in the Cup Holder position in a XC90 with sun roof with car ID DUG662. Since the Shark Fin in the car behaves quite poorly these measurements could only be performed in stepped mode.

3.2.3.5 SIMO with prototype integrated antenna

To further test the method and to investigating the change in system performance with different antennas a prototype antenna was tested. The antenna is intended to be a prototype for an antenna integrated in the spoiler or the instrument panel of the car. The prototype antenna was a combined V2X and LTE antenna with the LTE elements being planar inverted F-antennas(PIFA). It was tested mounted inside of the back window, below the spoiler and on the instrument panel, see figure 3.10. Connection between the CMW and the DUT could not be established with the prototype antenna at all.



(a) Instrument Panel

(b) Spoiler

Figure 3.10: The mounting of the prototype antenna intended for integration mounted on the instrument panel, figure 3.10a, and below the spoiler, 3.10b.

4

Results

4.1 Passive Measurements

The results of the measurements performed with the VNA.

4.1.1 Initial Passive Measurements

The first measurements performed were passive measurement with the VNA measuring the frequency response of the Scientific Atlanta Standard Gain Horn. Since the Standard Gain Horn has known and calibrated gain for 1.7-2.6 GHz, these measurements were used as reference to calculate the absolute gain for subsequent measurements. Figure 4.1 shows S_{21} measurements of the Standard Gain Horn with both the Log Periodic as transmitter antenna and the Bowtie as transmitter antenna, measured at 0°.

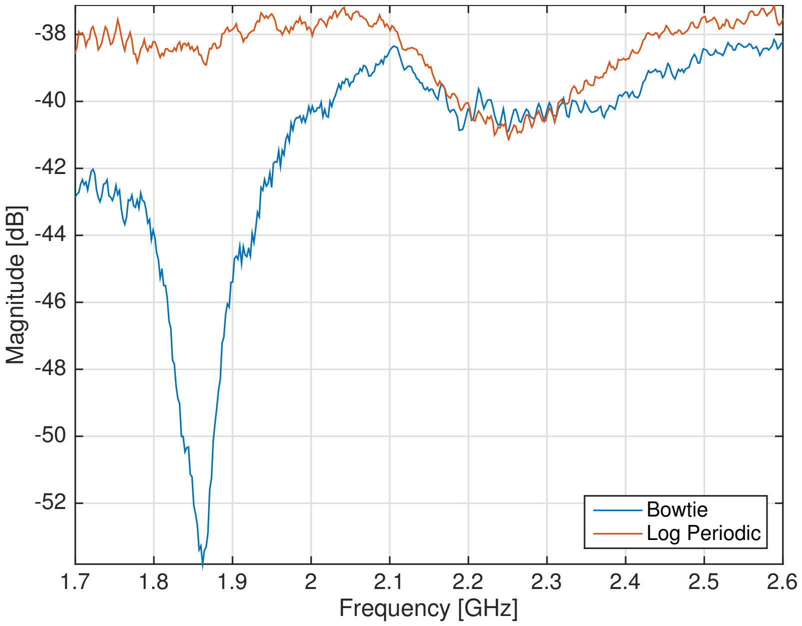


Figure 4.1: Frequency response of S21 with the two different transmitter antennas used in the thesis on the Standard Gain Horn used as reference. Measured at 0°.

Figure 4.3 shows the measured radiation patterns for the omni directional discone antenna. The Radiation patterns are measured for 1.7-2.6 GHz and they are plotted for 1.7 GHz and 2.6 GHz. They were measured with and without absorbers on the

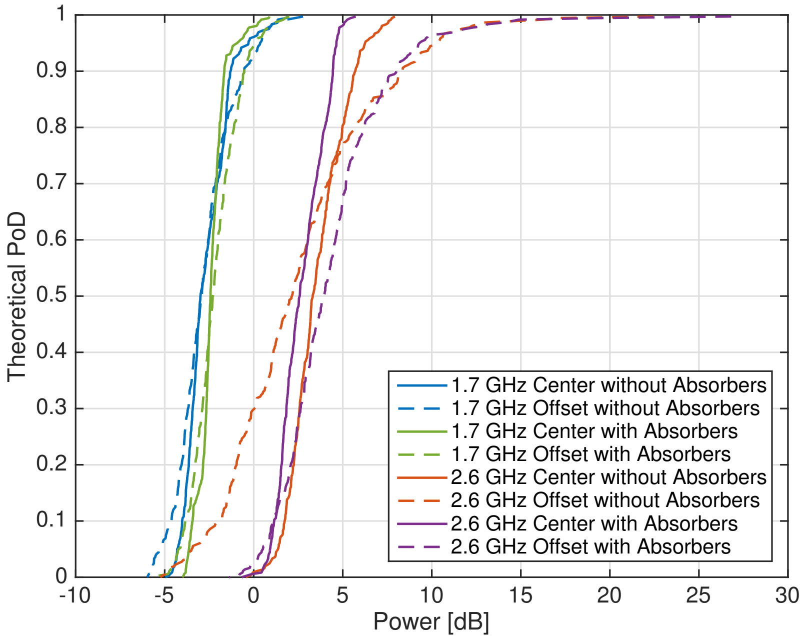


Figure 4.2: Theoretical calculated PoD of the discone antenna from the radiation pattern measurements.

ground and with the receiver antenna centered at the turntable as well as offset from the center by 160 cm.

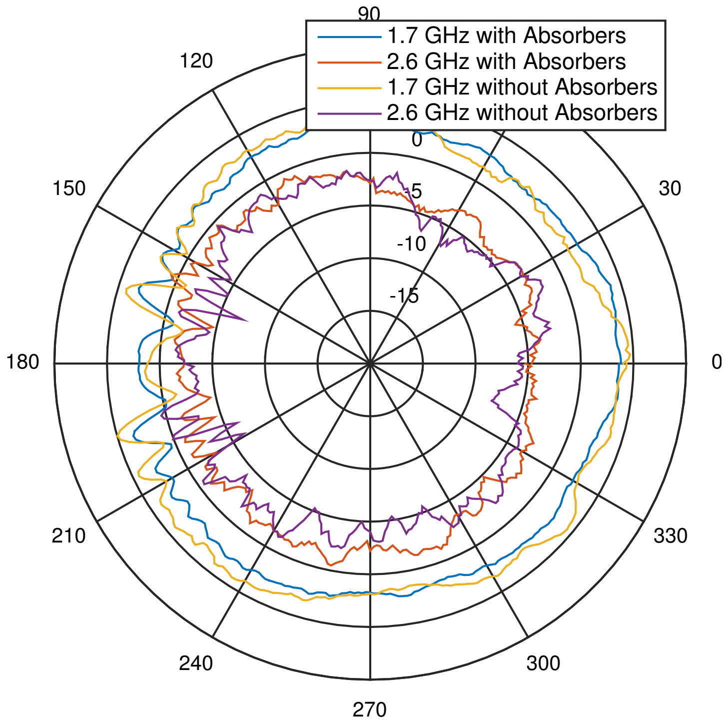
Figure 4.2 shows the theoretically calculated Probability of Detection curves calculated from the radiation pattern measurements. Plotted are the lower and upper parts of the frequency band, both offset and centered. All measurements are done both with and without absorbers.

Figure 4.4 shows the measurement with the spectrum analyzer of the air at the Volvo range. The peak in the spectrum fits quite well to the dip in figure 4.1 with the bowtie antenna.

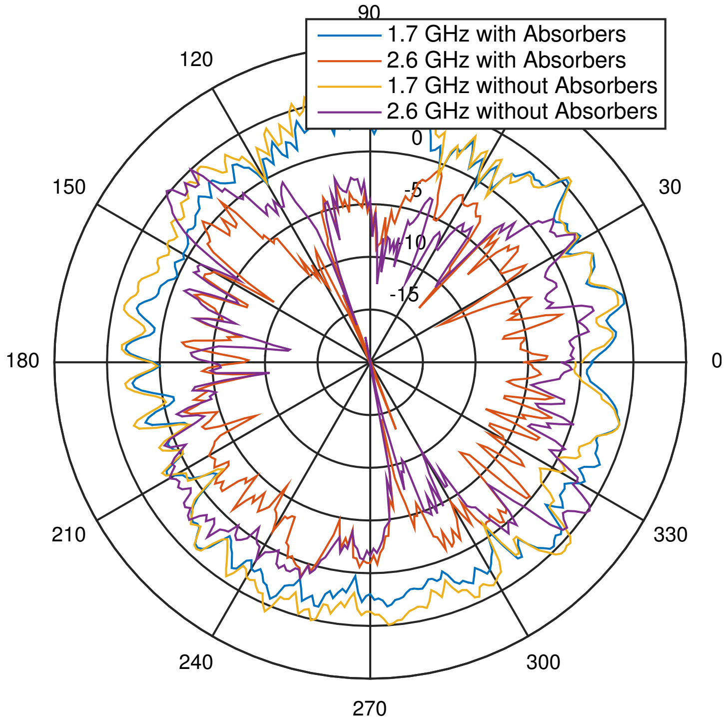
Based on these measurements the band and channel used for the active measurements avoided the dip shown in the bowtie measurement in figure 4.1 and at the same time use as low frequency as possible to avoid the multipath effects at higher frequencies. Band 1 channel 490 was chosen, it uses 2169 MHz for the downlink and 1969 MHz for the uplink.

4.1.2 Passive Measurements at Volvo compared to Active measurements at Chalmers

Figure 4.5 shows the theoretically calculated PoD curves for passive measurements of the Shark Fin antenna mounted on a tripod in the center of the turntable with the smaller square ground plane and the larger round ground plane. The theoretical PoD curves are plotted for 1.7 GHz and 2.6 GHz and measured at Volvos range. For comparison, PoD curves from throughput measurements performed in Chalmers Anechoic Chamber performed by Madeleine Schilliger Kildal[17] are also plotted. The throughput measurements and the passive measurements are intentionally offset from each other. However the difference between LTE 1 and LTE 2 measurements



(a) Centered



(b) Offset

Figure 4.3: The radiation pattern(in dBi) for the Omnidirectional discone antenna for the edge frequencies and with and without absorbers for ground reflections. In plot 4.3a the antenna is in the center of the turntable and in 4.3b it is offset from the center by 160 cm

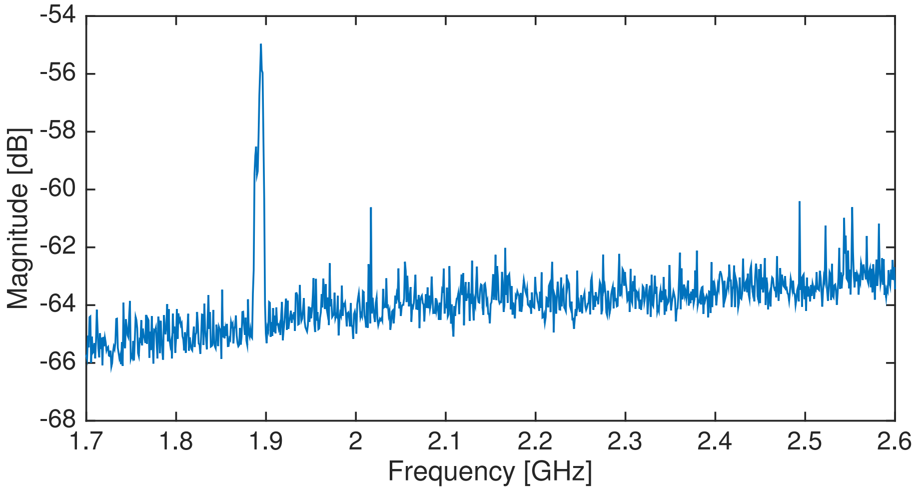
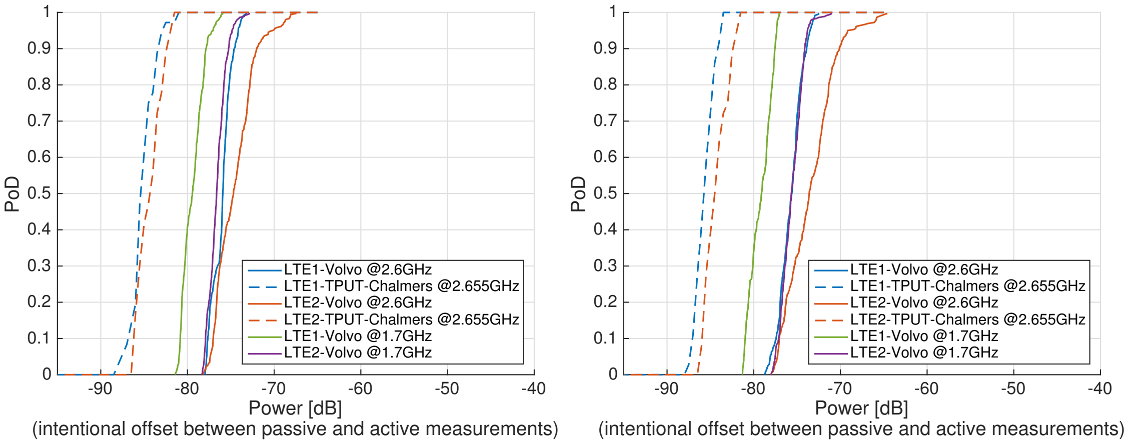


Figure 4.4: The measured spectrum at the Volvo range.



(a) Round Ground Plane

(b) Square Ground Plane

Figure 4.5: Theoretical PoD for Shark Fin antenna mounted on a tripod measured at Volvo and throughput measurement performed at Chalmers Anechoic Chamber.

are internally correct for the active and passive measurements.

4.2 Active Measurements

The results of the measurements performed with the CMW500 Communication tester.

4.2.1 Stepped and Continuous mode

Figure 4.7 shows the plots of the PoD curves for Stepped mode and Continuous mode measurements. For the stepped mode, 15 samples at stationary angle at each power level, was collected. The PoDs have been calculated with a method in this thesis called Best Sample, where only the best sample of those 15 sample at each level was used, and with the average method, where the average of those 15 samples

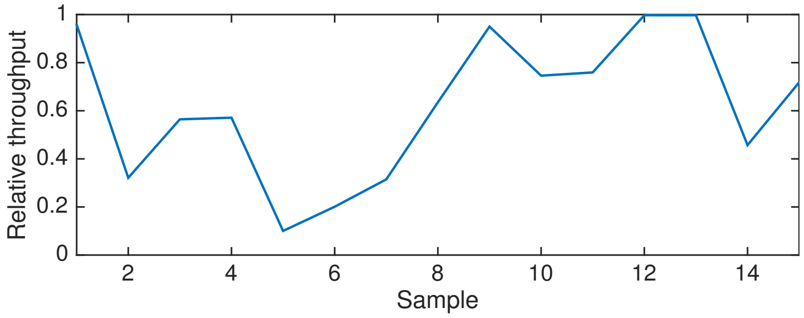


Figure 4.6: The 15 samples of one measurement at a fixed angle and power.

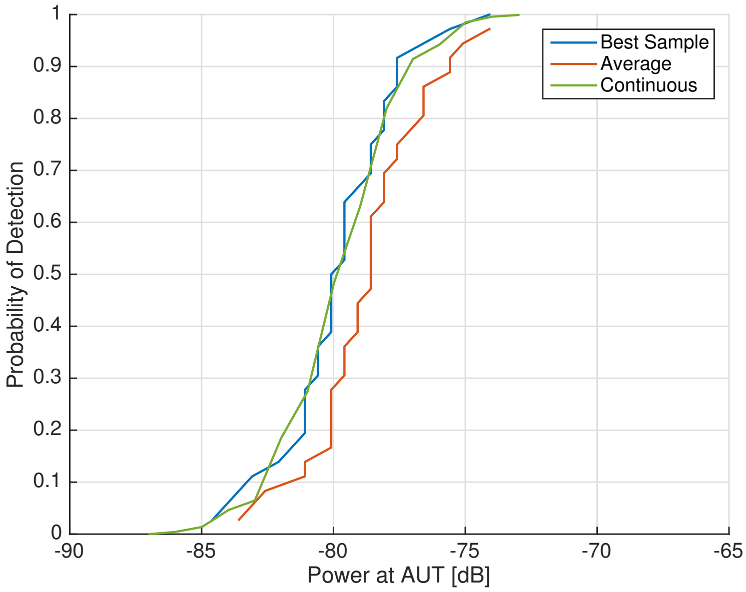


Figure 4.7: Comparison of the stepped and continuous mode and the best sample and average mode of data handling for the stepped mode.

was used. Figure 4.6 show an example of a 15 sample measurement done at a fixed angle and fixed output power, for the best sample one of the samples with 100 % throughput is used and for the average, the average of all the of the 15 samples is used. For the stepped mode each power increment was 0.5 dB and for continuous mode the power was decrease with 1 dB steps.

Figure 4.8 shows different amount of the samples from continuous mode measurement used to calculate the PoD. The same measurement is used and the samples are evenly distributed around the car.

4.2.2 Interference in Stepped mode

Figure 4.9 shows the PoD curves for a SIMO measurement where the best, the worst, and the average of all samples has been used to calculate the threshold. The difference between the worst and best sample shows the effects of the interference in the unshielded open range.

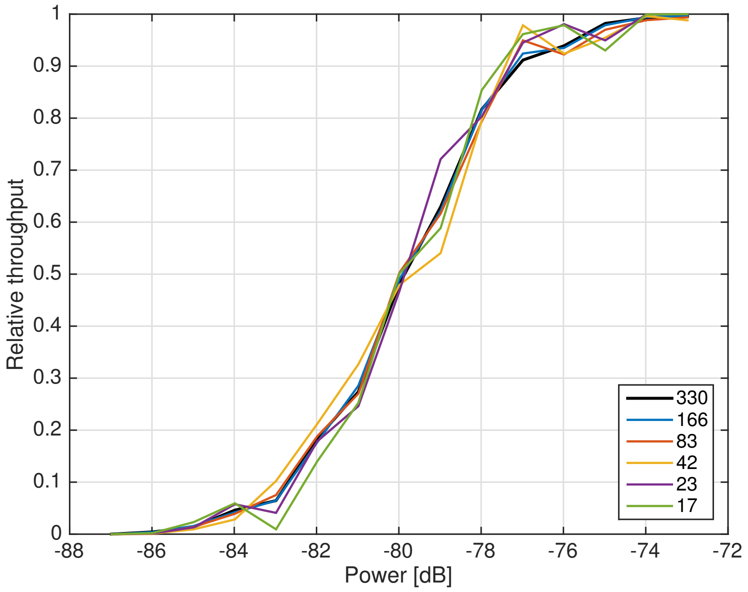


Figure 4.8: Comparison of using different amount of samples at each power level for the continuous mode.

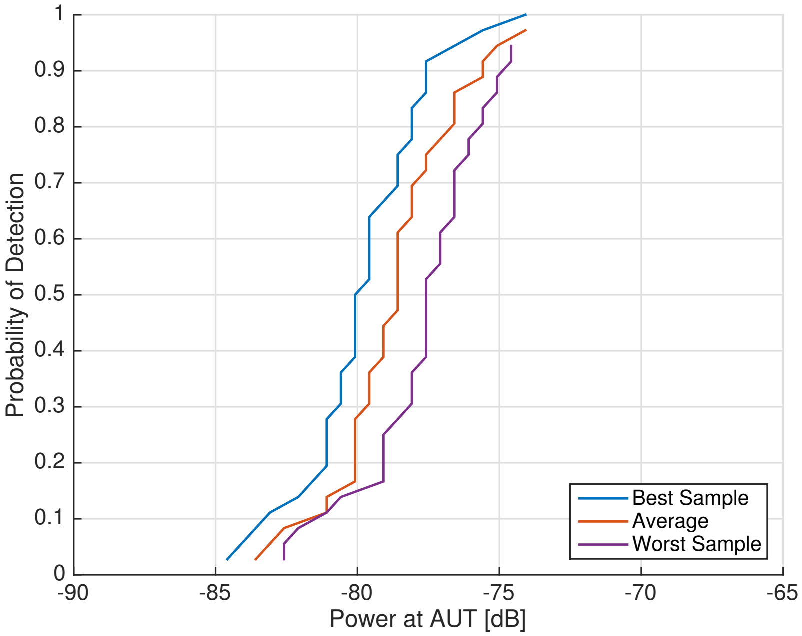


Figure 4.9: Comparison of the best and worst sample and the average of all samples for a single measurement.

4.2.3 Active SISO and SIMO

Figure 4.10 show measurements of the Shark Fin antenna mounted on a XC90 comparing SISO for the two LTE antennas in the Shark Fin, called to LTE 1 and LTE 2, and the SIMO measurements of the Shark Fin antenna. The reference measurement is a SISO measurement with the Standard Gain Horn and the measurements plotted relative to an isotropic antenna. The measurements done with the Stepped mode

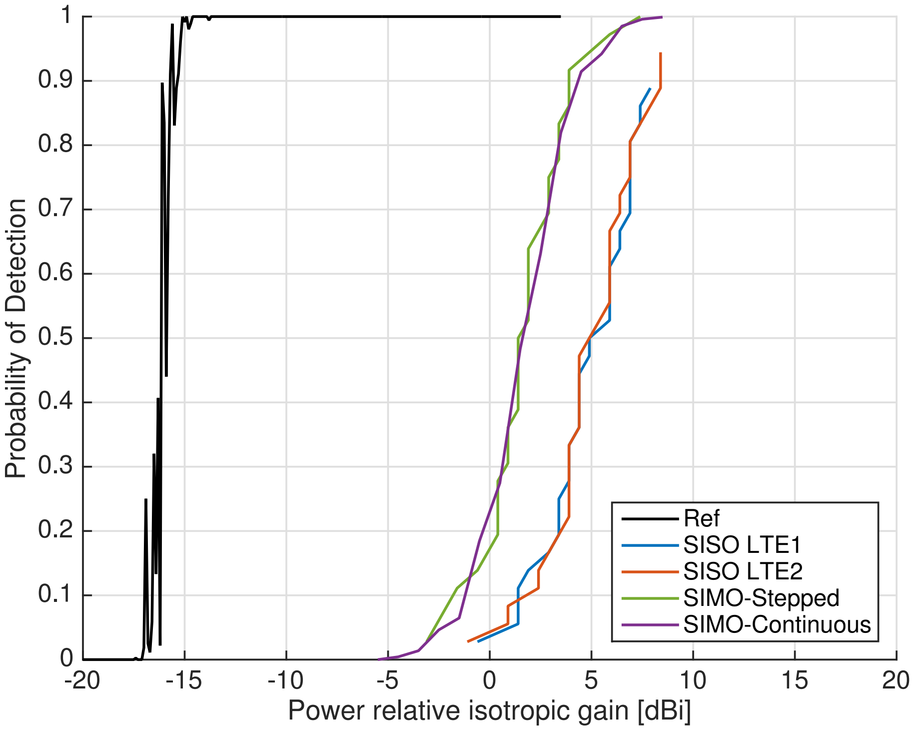


Figure 4.10: Throughput measurements for Shark Fin mounted on XC90.

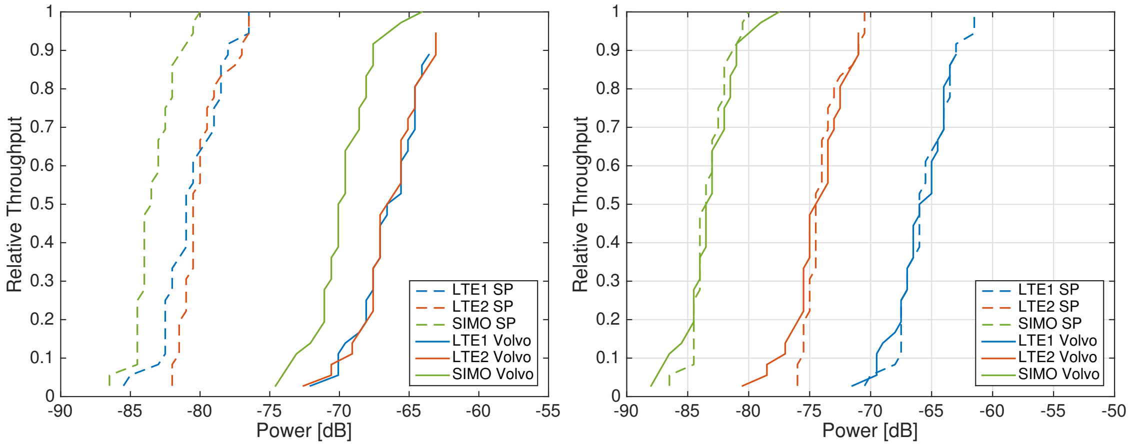
are plotted with the Best Sample method.

4.2.4 Comparison Volvo range to SP range

With a similar setup Madeleine Schilliger Kildal has performed measurements in SP's semi anechoic chamber[10]. The measurements were performed at channel 3100 which is outside the band of the reference used in this thesis. Channel 3100 translates to a downlink at 2655 MHz compared to channel 490 used in this thesis with a downlink at 2159 MHz. The shift in frequency changes the threshold of the used dongle and performance of the antenna. The SP chamber is equipped with a large turntable, where the antenna can be placed in the center, even when mounted on a car. The results are shown in figure 4.11. In figure 4.11a are the measurements intentionally offset since the absolute values are not comparable. The shape of the PoD and internal distribution can be compared since they are effected by the chamber. In figure 4.11b are the measurements aligned at the 50% level to more easily compare the shapes of the probability of detection curves.

4.2.5 Antenna positions

The Shark Fin antenna was placed on the cup holder inside the car to measure the effects of the body, see figure 3.9. Figure 4.12 shows the measured PoD curves. However since the output power of the CMW500 is limited to -15 dBm complete PoD curve could not be measured. The power in the figure is relative to an isotropic antenna calculated from the reference, the Standard Gain Horn. Figure 4.13 shows a Rayleigh CDF plotted as PoD and fitted to the measured data of the Shark Fin



(a) (b)

Figure 4.11: The PoD curves for the Shark Fin mounted on a XC90 measured at both Volvo and SP. In figure 4.11a the Measurements are intentionally offset from each other since they were done for different frequencies and in figure 4.11b they are aligned at the 50% level for each measurement.

mounted on the cup holder inside the car. Rayleigh CDF would have been a good fit in RIMP enviroment, but in the RLOS with the antenna inside the car, the car will create a multipath enviroment, but there will be a Line-of-Sight component. The roof mounted antenna is in a line-of-sight environment and a Rayleigh is a bad fit. Fitting a curve which looks like a RLOS PoD curve normally do, $\log_{10}(1 - e^{-x^2/2\sigma^2})$, works quite well. This is a very rough guess, it indicates however that at the 95% level there are a 7.5 dB difference with having the antenna inside or outside of the car.

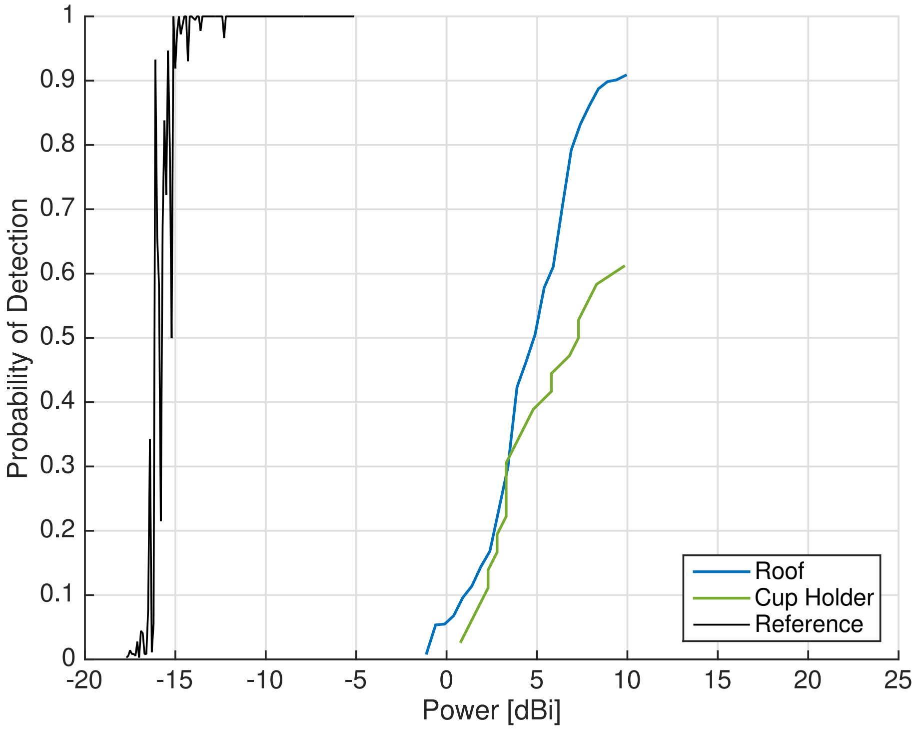


Figure 4.12: SIMO measurements of the Shark Fin mounted on the roof and compared with mounted on the Cup Holder inside the car. The reference is the Standard Gain Horn. The power is relative isotropic an antenna.

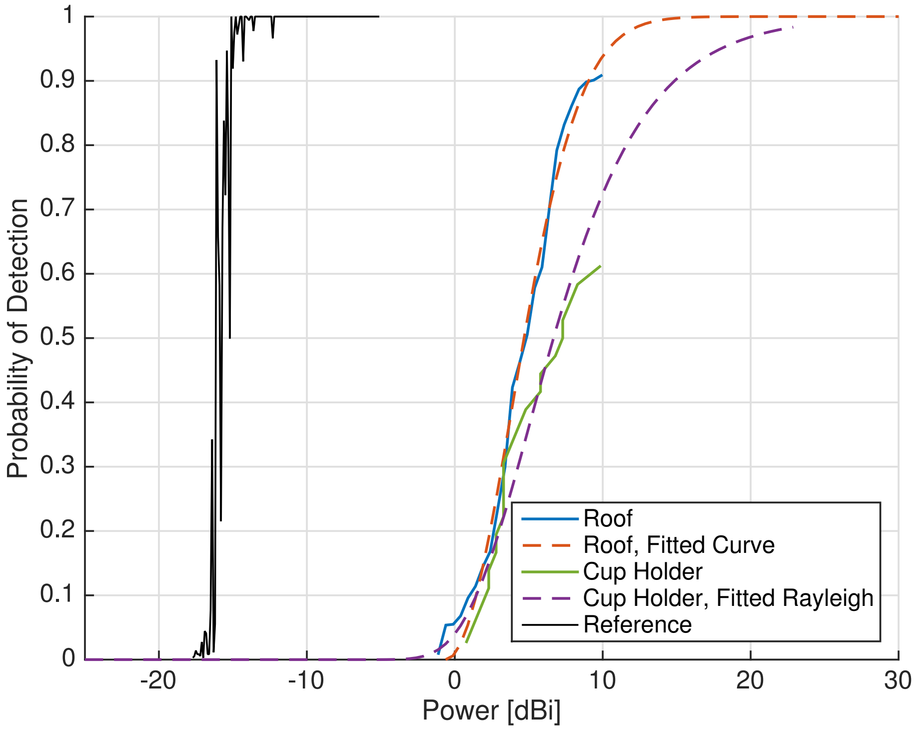


Figure 4.13: The measurement of the Shark Fin mounted on the roof and on the cup holder as well as fitted curves. The reference is the Standard Gain Horn. The power is relative isotropic an antenna.

5

Discussion and Conclusions

5.1 Discussion

5.1.1 Multipath and Interference

The Volvo antenna measurement range is an open range, with no absorbers or RF shielding. The measurements in figure 4.3 and 4.2 indicate that there are reflections at the range. When the antenna is offset from the center of the turntable, since the antenna is omnidirectional the radiation pattern should only change with the distance between the transmitter antenna and the receiver antenna. However comparing figure 4.3a and 4.3b shows that at especially at higher frequencies this is not the case at this range. By looking at the calculated PoD curves from the measured radiation patterns in figure 4.2, it can be seen that the offset curves are closer to Rayleigh distribution than the centered curves. This means that the environment change when the antenna is moved in space, this would not be the case if the there would be a pure line-of-sight environment.

Figure 4.2 and 4.3 shows curves for measurements both with and without absorbers on the ground. It is apparent that the increased frequency has a larger effect than the absorbers and if there are ground reflections, the relative small amount of absorbers available has small effect on the measurements at the relevant frequencies.

Figure 4.9 show the PoD curves for a SIMO measurement performed in stepped mode with the PoD curves calculated with the best sample method, average method and the worst sample method. The worst sample method is similar to the best sample method but is uses the worst sample instead of the best sample. In a well shielded anechoic chamber the three curves would be identical, however the difference between the best sample and worst sample PoD curves is approximatly 3 dB and is the effect of interference.

Figure 4.5 shows measurements from Chalmers anechoic chamber compared with measurements from Volvos open range. The measurements from Chalmers are active and the ones from Volvo are passive. Since it is comparing active to passive measurements only the difference between LTE 1 and LTE 2 and the shape of the curves are interesting. The difference between LTE 1 and LTE 2 is approximately 1.5 dB larger for the Volvo measurements than for the Chalmers measurements. The difference could be from the difference between the two chambers. The Volvo range introduce a lot of multipath and interference, the difference is less than the shown 3 dB performance difference from the interference.

To be able to perform line-of-sight measurement at the Volvo range, of the frequencies tested, low frequencies should be used to keep the multipath contribution to a minimum. However looking at a measurement of the standard gain horn antenna with a Bowtie as transmitter, figure 4.1, the frequencies between 1.8-1.9 GHz should be avoided since the Bowtie shows a 10 dB dip at those frequencies in this environment. This dip is most likely an effect of interference, in figure 4.4, where a spectrum analyzer was used to try to measure the interference in the air at the Volvo range, it shows a strong signal at 1.89 GHz. However even when keeping the multipath contribution to a minimum the interference limits, as shown, the precision of the measurements. The combination of reflections at the site and the interference limits the frequencies that can be used for measurements.

5.1.2 Stepped or Continuous mode measurement

Looking at figure 4.7 where Stepped or Continuous mode measurements are compared it is clear that the continuous mode measurements are very comparable to the best sample method of the stepped mode measurement. Even though the Continuous mode used a 1 dB resolution for the power sweep and the stepped mode used a 0.5 dB resolution for the measurements.

The Continuous mode is faster than the stepped mode and in this environment comparable in accuracy. Since the turntable at the Volvo measurement site can not be controlled remotely, only monitored, it is the preferred method since it is a much more automated process. Figure 4.8, where less samples were used, indicate that continuous mode could be run faster with less samples and still give a quite accurate result.

The downside of using the continuous mode is that if you measure on an antenna with low dips in its radiation pattern such as a directive antenna or the antenna placed inside of the car the communication tester might loose connection to the DUT at high power levels in some direction. For the continuous mode you need to be able to stay connected for the entire 360° turn for each power level that are of interest. With the stepped mode the power sweep for each angle can be stopped after the level of 0 % throughput has been reached and it is assumed that for all lower output levels the throughput are 0 %. This makes the stepped mode more suitable for antennas with directive radiation pattern.

5.1.3 Use of isotropic reference

It is not established how measurements done with RLOS should be referenced to is not well established, referencing to an isotropic antenna was introduced in this thesis. In some previous work the self grounded bowtie has been used as a reference antenna[17][10]. With the isotropic reference the maximum gain from a radiation pattern measurement should be of the same level as the 0 % level of the PoD, the maxium gain is the negative power level at the 0 % level of the PoD. In figure 4.10, the gain at the 2 % level is 0.6 dBi. If it would linearly continue to the 0 % it would become 2.8 dBi. Most likely it would be higher if measured assuming it follows a similar trend as the SISO case. Comparing to normal radiation pattern measurement of the sam antenna it has a maximum gain of 3.3 dBi. The difference is 0.5 dB.

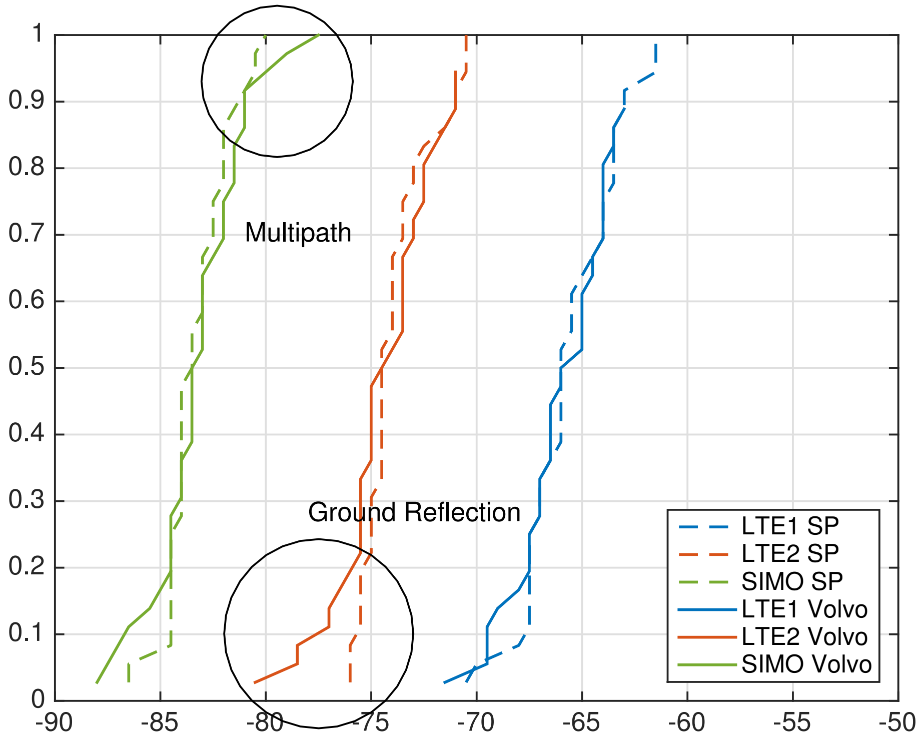


Figure 5.1: Indications of increased ground reflections and multipath contribution at the Volvo range compared to the SP chamber.

5.1.4 Effects from the use of SIMO

Figure 4.10 shows the measurements for the Shark Fin used in SISO mode for LTE antenna 1 and 2 and in SIMO mode. In SISO mode the two antennas perform very similarly to each other but using both antennas in SIMO mode it performs 4.5 dB better at the 90 % level than in SISO. This is a clear performance improvement in a line-of-sight scenario that can not be measured with classical antenna measurements.

5.1.5 Difference between Volvos open range and SP semi anechoic chamber

Since the measurements presented in figure 4.11 with PoD curves measured at both the Volvo open range and the semi anechoic chamber are measured at different frequencies they should not be equal. By comparing the conducted threshold the difference in performance for the DUT could be compensated. However, the gain of Shark Fin at both frequencies, for all angles and with the slight difference in height between the transmit antenna at Volvo and SP is not known and can not be compensated for to look only at the performance difference of the Volvo range to the SP chamber.

Looking at figure 4.11b where the shape of the PoD curves are compared, the curves from Volvo go to much lower powers for low probability of detection levels than the SP measurements, see figure 5.1. This is most likely due to a ground reflection that is not present at SP. A ground reflection with positive interference can increase the gain for a specific distance between the transmitter and receiver and the lower left level represent the maximum gain.

At the upper end of the SIMO PoD curve the measurement from Volvo requires higher power, see figure 5.1, which indicates that there are multipath effects at the Volvo range which are not present at the SP chamber, which is expected. Since the CMW500 lacked enough output power to complete the SISO measurements up to the 100 % level this behavior would most likley be present for the SISO LTE 1 and LTE 2 antenna.

Comparing the measurements performed at SP[10], see figure 4.11a, where the difference between SISO and SIMO at SP was 3.1 dB and at Volvo with the difference of 4.5 dB, even if they are at different frequencies they only differ by 1.4 dB. 1.4 dB is less than the effect seen by the interference at Volvo.

5.1.6 Using Random-LOS for evaluating antenna placement

Comparing antenna diagrams for antennas that are close to omnidirectional to evaluate random-LOS performance is hard. When you have two antennas that combined is used for SIMO or MIMO, it gets even harder to evaluate performance by studying radiation pattern measurements. Figure 4.13 shows the PoD curves for SIMO measurements for both the Shark Fin mounted on the car and inside the car. As the fitted curves are not exact, these measurements should be treated as proof of concept for the random line-of-sight measurement method. At the 95 % level the shark fin performs 7.5 dB worse inside the car and 6 dB at the 90 % level. A very clear measure of the performance difference for multi port antenna with the effect of moving it inside. The performance is effected by the increased multipath from the car itself and its interior when the antenna is moved inside the car.

5.2 Conclusions

The RLOS method can be used to evaluate system performance or performance of individual subsystems. It can measure the performance of multi port antennas with receive diversity and as shown in other papers, MIMO performance[17] in Line-of-Sight. It is clear that this method can be used for comparing the performance of an antenna mounted inside the car to a roof mounted antenna. Even though the output power of the used setup was too low for a complete measurement, the performance difference between using a roof mounted antenna and an antenna in the car was approximated to 7.5 dB for 95 % probability of detection. In the same manner the method can be used for comparing the performance of a car with the performance of a phone or tablet inside of the car.

Especially from the passive measurements it is clear that for especially higher frequencies the Volvo measurement range is far from anechoic. For the frequency band measured it is clear that lower frequencies performs closer to pure LOS. However at around 1.8-1.9 GHz there are a lot of interference, it is measured with a spectrum analyzer to be at 1.89 GHz, figure 4.4, at a specific time. Even when avoid the 1.8-1.9 GHz interference, a lot of interference can be seen in in the static throughput measurements, figure 4.6, and the difference between best and worst sample 4.9 is a result of interference. Measurements at the range can be performed, however there are substantial difference in the environment for different frequencies. If there is a need to measure several frequencies band and compare their performance a shielded chamber is most likely required to get reliable and repeatable results.

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A

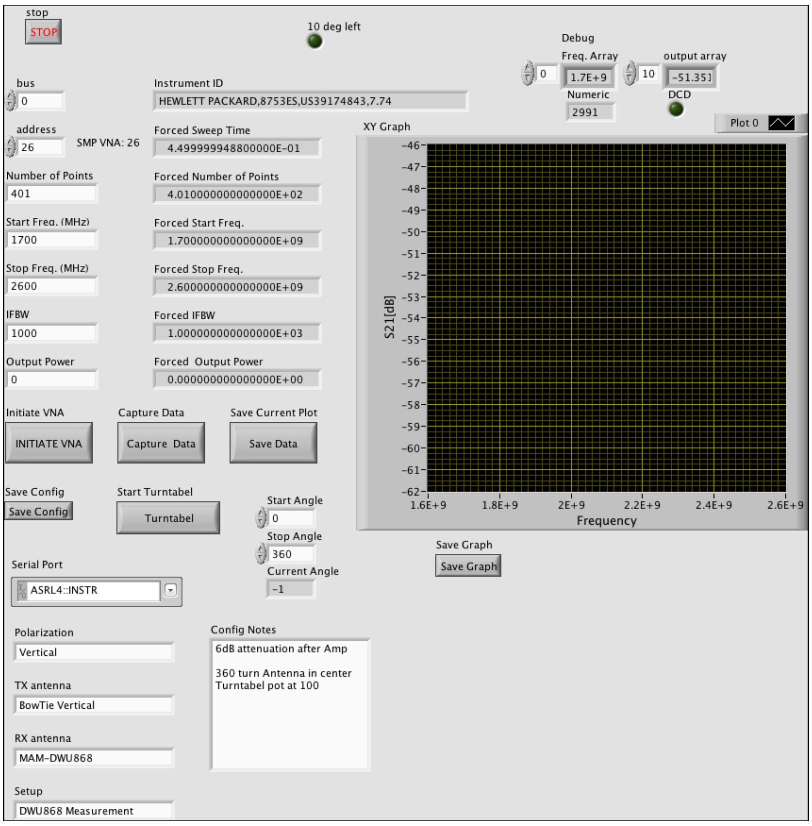
Source Code for the Measurement Tools Developed

A.1 Passive Measurements

The source code for the tools developed and used as part of the thesis to perform the passive measurements in this thesis is published at `https://github.com/kses/RLOS-VNA-Controller`. It includes several tools for data collection and data viewing.

A.1.1 VNA Controller

Main tool used when performing passive measurements, used for collecting data. Capable of listning to the turntable used in the project, figure A.1.



Freq. Array
0
1.7E+9

output array
10
-51.351

Numeric
2991

bus
0

Instrument ID
HEWLETT PACKARD,8753ES,US39174843,7.74

address
26
SMP VNA: 26

Forced Sweep Time
4.499999948800000E-01

Number of Points
401

Forced Number of Points
4.010000000000000E+02

Start Freq. (MHz)
1700

Forced Start Freq.
1.700000000000000E+09

Stop Freq. (MHz)
2600

Forced Stop Freq.
2.600000000000000E+09

IFBW
1000

Forced IFBW
1.000000000000000E+03

Output Power
0

Forced Output Power
0.000000000000000E+00

Start Angle
0

Stop Angle
360

Current Angle
-1

Serial Port
ASRL4::INSTR

Polarization
Vertical

Config Notes
6dB attenuation after Amp

360 turn Antenna in center
Turntabel pot at 100

TX antenna
BowTie Vertical

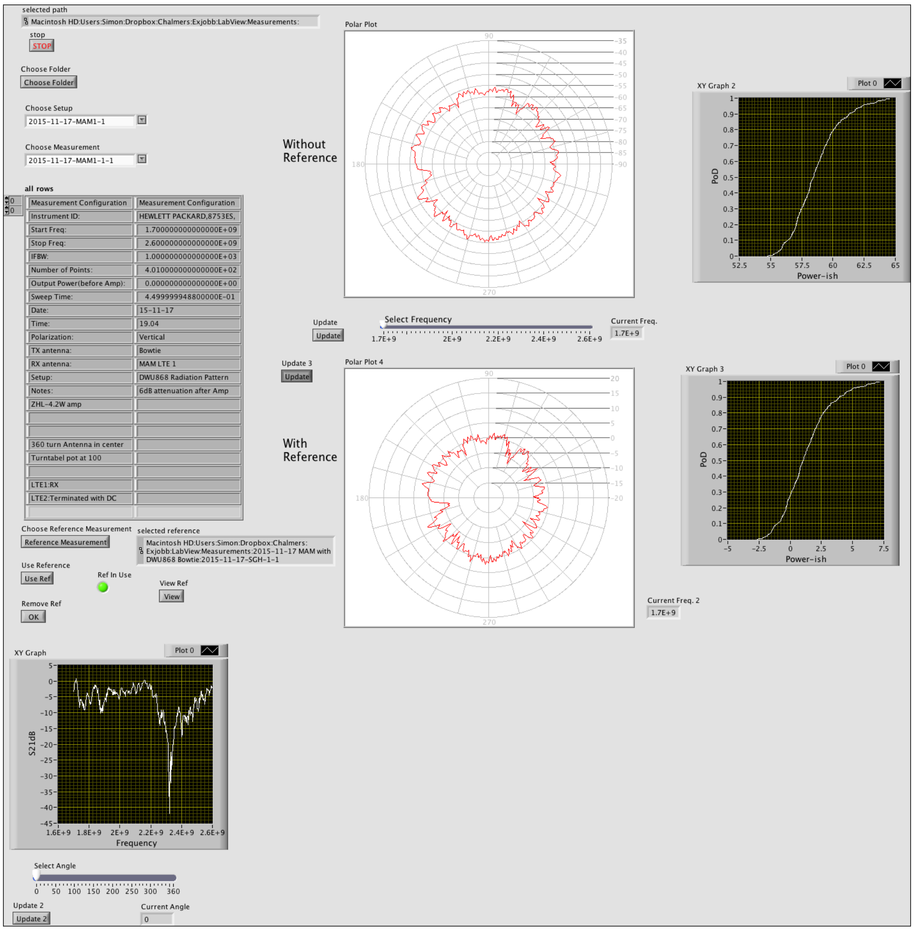
RX antenna
MAM-DWU868

Setup
DWU868 Measurement

Figure A.1: Screenshot of the VNA control tool.

A.1.2 Data Viewer

Used for displaying and interacting with data. Used for initial data analysis. Shows both radiation pattern and theoretical PoD of the measurements for the frequency range used, figuer A.2.



selected path: Macintosh HD:Users:Simon:Dropbox:Chalmers:Exjobb:LabView:Measurements:

Choose Setup: 2015-11-17-MAM1-1

Choose Measurement: 2015-11-17-MAM1-1-1

all rows

Measurement Configuration	Measurement Configuration
Instrument ID:	HEWLETT PACKARD,8753ES,
Start Freq:	1.700000000000000E+09
Stop Freq:	2.600000000000000E+09
IFBW:	1.000000000000000E+03
Number of Points:	4.010000000000000E+02
Output Power(before Amp):	0.000000000000000E+00
Sweep Time:	4.499999948800000E-01
Date:	15-11-17
Time:	19.04
Polarization:	Vertical
TX antenna:	Bowtie
RX antenna:	MAM LTE 1
Setup:	DWU868 Radiation Pattern
Notes:	6dB attenuation after Amp
ZHL-4.2W amp	
360 turn Antenna in center	
Turntabel pot at 100	
LTE1:RX	
LTE2:Terminated with DC	

selected reference: Macintosh HD:Users:Simon:Dropbox:Chalmers:Exjobb:LabView:Measurements:2015-11-17 MAM with DWU868 Bowtie:2015-11-17-SGH-1-1

Current Freq.: 1.7E+9

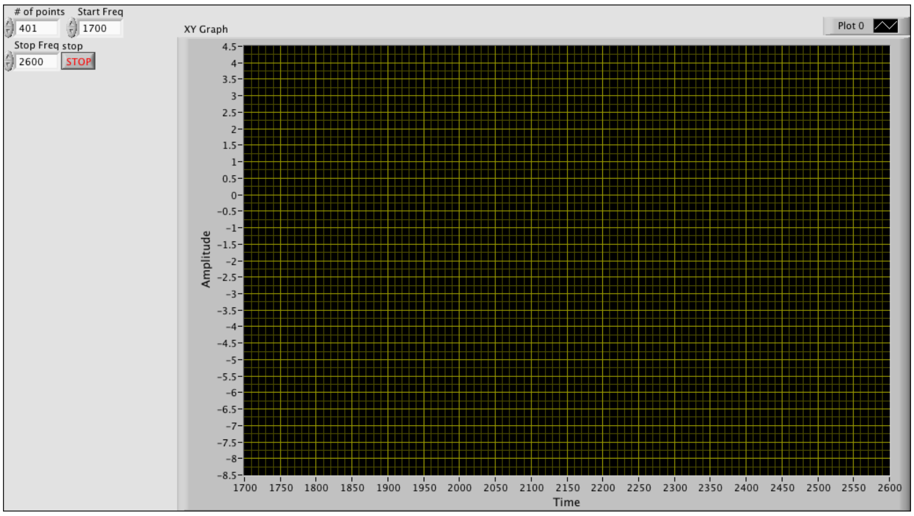
Current Freq. 2: 1.7E+9

Current Angle: 0

Figure A.2: Screenshot of the Data Viewer tool.

A.1.3 VNA Viewer

Used for monitoring the VNA from a remote location, inside the measurement tent when the VNA is located in the control room, using VNC software and WiFi, figure A.3.



# of points: 401
Start Freq: 1700
Stop Freq: 2600

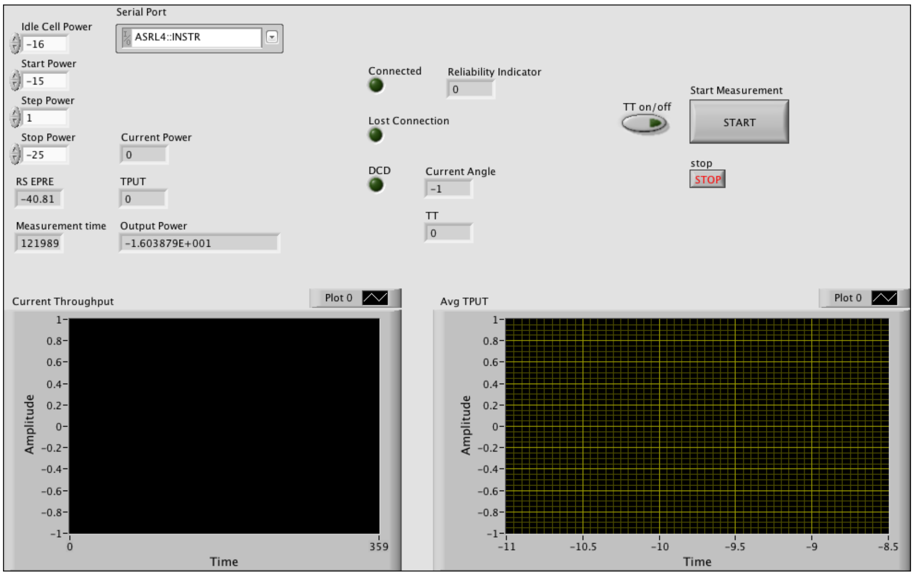
Figure A.3: Screenshot of the VNA viewer.

A.2 Active Measurements

The source code for the tools developed and used as part of the thesis to perform the active measurements in this thesis is published at `https://github.com/kses/RLOS-CMW500-Controller`. It includes the main measurement tool and a few smaller tools. Used for initializing the CMW500 software was Bluetests Measurement Suite.

A.3 CMW500 Controller

The software used for performing the active measurements, figure A.4.



Idle Cell Power: -16
Serial Port: ASRL4::INSTR
Start Power: -15
Step Power: 1
Stop Power: -25
Current Power: 0
RS EPRE: -40.81
TPUT: 0
Measurement time: 121989
Output Power: -1.603879E+001
Reliability Indicator: 0
Current Angle: -1
TT: 0

Figure A.4: Screenshot of the CMW500 Controller software.

A.4 Smaller tools

The smaller tools used during setup and testing were the IDN tester, used for testing communications between the measurement equipment, and the VNA reference collector, used for taking calibration measurement with the VNA to calibrate the CMW500 setup. Source code for both can be downloaded from the linked repository.