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TEST CASE IMPROVEMENT FOR 5G BEAMFORMING MEASUREMENTS

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ABSTRACT

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The target of this thesis was to develop and improve a test automation test case which is used to measure 5G NR beamforming for Nokia's 5G products. The goal of test case was to improve measurement results based on a previously used test case. The theory part of the thesis briefly covers what is 5G NR and beamforming.

As a result of this thesis, Nokia has now a better test case to measure 5G NR beamforming. The new test case provides more accurate test results and a base for implementing further test automation.

The test case was created, and the measurements reports were documented. These are Nokia's internal documents and not included in this thesis. Although, some results are shown without power levels and simulations generated for those results.

Keywords: 5G, OTA testing, Beamforming

ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
DUT	Device Under Testing
eMBB	enhance Mobile Broadband
IoT	Internet of Things
mMTC	massive Machine-Type Communication
NR	New Radio
OTAVA	Over The Air Validation Area
OTA	Over The Air
PCB	Printed Circuit Board
RF	Radio Frequency
SINR	Signal-to-Interference-and-Noise Ratio
SSB	Synchronization Signal Block
UE	User Equipment
URLLC	Ultra-Reliable Low Latency Communication

CONTENTS

1 INTRODUCTION

Nokia is the biggest technology company in Finland. Nokia employs more than 90,000 people across the world, of which more than 6,000 work in Finland. In addition to Oulu, Nokia has also offices in Espoo and Tampere. Oulu has a total of about 2,700 employees, most of whom work in research and development [1].

The Oulu site, “Home of Radio”, consist of two very close facilities: Rusko Campus and Over the Air Validation Area (OTAVA). OTAVA is Nokia’s biggest test laboratory. There are dozens of RF anechoic chamber test lines and multiple antenna walls in the OTAVA test laboratory to test 5G products, user equipment (UE) and other RF-related equipment [2].

1.1 Scope and Objectives

The scope of this thesis was to improve a test automation test case, which is used to measure 5G NR beamforming for Nokia’s 5G products. For this thesis these products are referred as a device under testing (DUT). The objective is to study error factors which produce measuring errors during the test case’s test run with a current test environment and test equipment. Based on the results of the study, a new test case is created, which improves the quality of the measurement results by considering the observed measurement errors created by the previous test case.

1.2 Structure of Thesis

After the introduction, chapter 2 briefly explain the basic background for this thesis about 5G NR and beamforming. Chapter 3 explains the test environment and testing with a current test case process to measure beamforming and flaws of the test case which produce error measurements. In chapter 4 a new test case design principles are presented. Chapter 5 goes through the test case’s testing process, and results are presented and evaluated. Finally, in chapter 6 the thesis is concluded with final thoughts of the work.

2 BACKGROUND

2.1 5G NR

5G NR is the 5th generation mobile network. It is predecessor to other wireless standard after 1G, 2G, 3G and 4G networks. The 5G NR technology enables enhaning mobile broadband (eMBB) capability by brining better performance with bigger data rates and increased capacity compared to the previous wireless standards. Together with low latency 5G NR makes it possible for ultra-reliable low latency communication (URLLC) such as vehicle to vehicle (V2) communication or a remote factory automation control. In addition, 5G NR is also capable to provide a flexible platform for new services for IoT and massive machine-type communication (mMTC) [FIGURE 1].

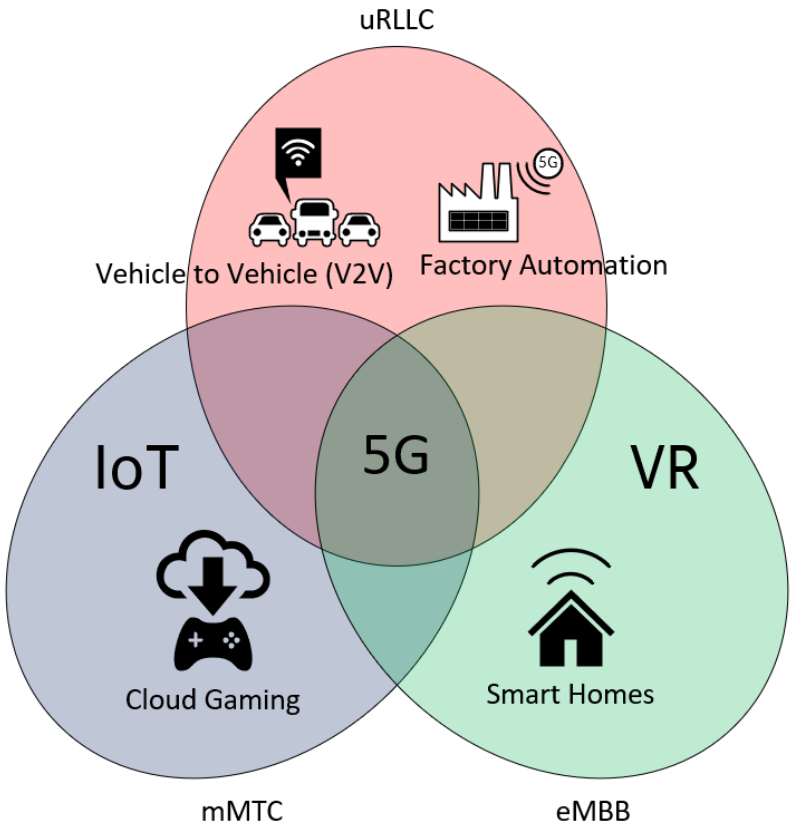

FIGURE 1. 5G NR use cases

2.2 Beamforming

Beamforming is essential for 5G NR, because it enhances network capacity, coverage and spectral efficiency. In general, beamforming uses multiple radiating elements to control the direction of a wavefront by transmitting the same signal at an identical wavelength and phase. The form of this effective radiation pattern is called the main lobe. By changing the phase of the signal on all radiating elements, it is possible to steer the beam in a specific direction [FIGURE 2]. This way it is possible to track the UE, and effectively reduce interference and improve the signal-to-interference-and-noise ratio (SINR).

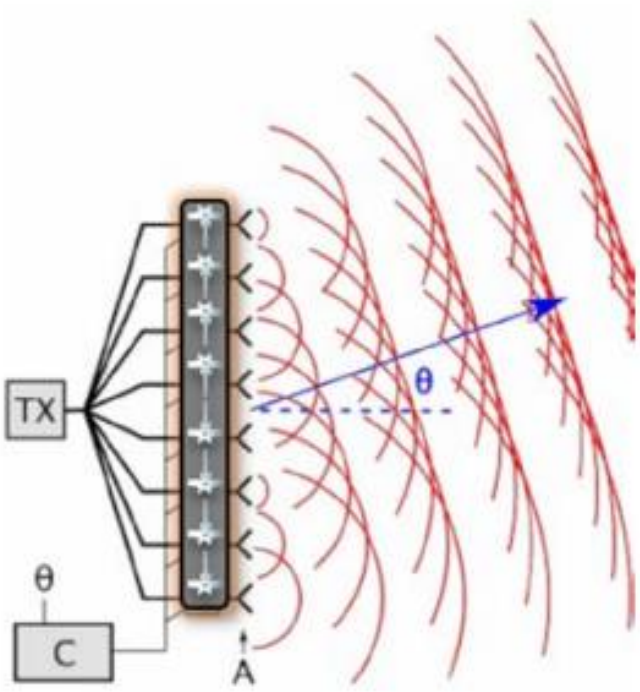

FIGURE 2. Effect of phase shift [4]

However, beamforming also generates side lobes and back lobes, which disperse the radiated power away from the main lobe and are usually representing unwanted radiation [FIGURE 3].

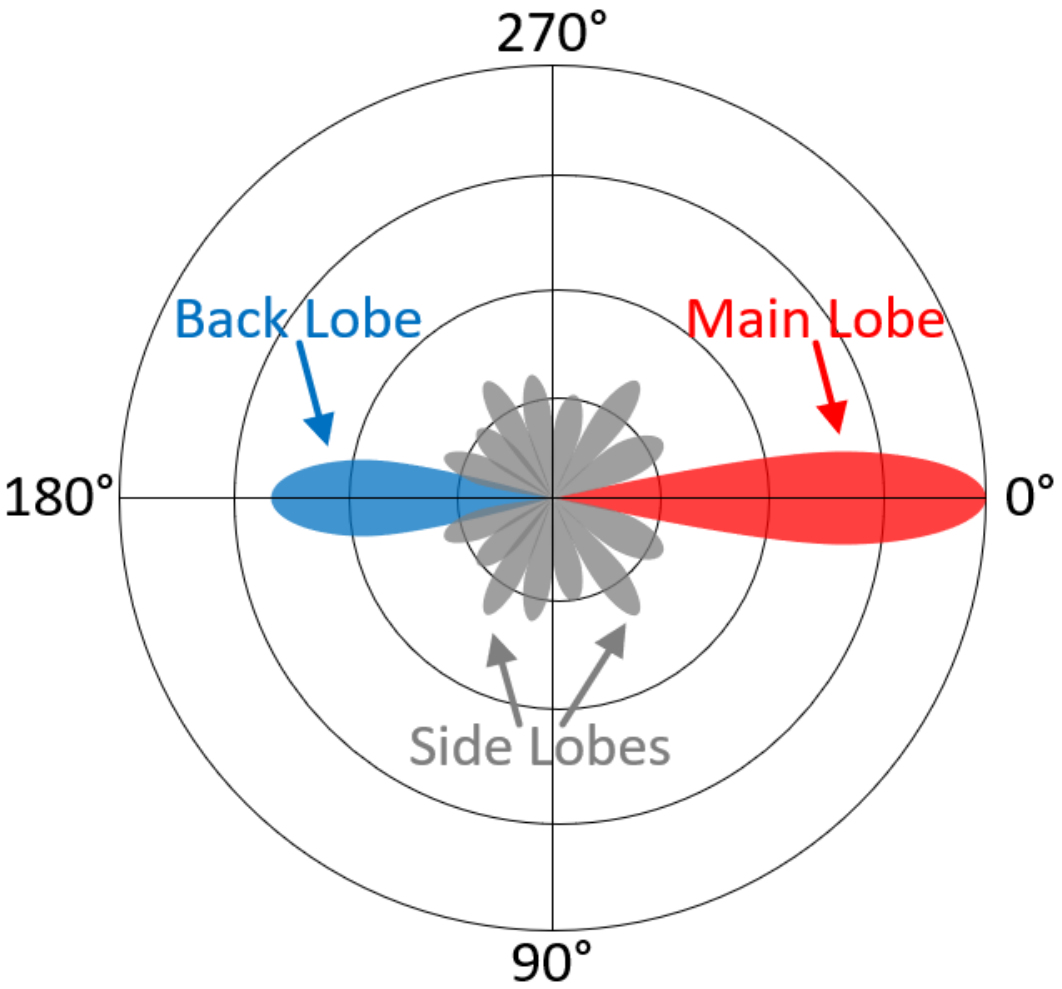

FIGURE 3. Radiation pattern of a beamformer showing main lobe, back lobe, and side lobes.

3 TESTING WITH THE CURRENT TEST CASE

3.1 Test Environment

The beamforming measurements are performed at Nokia's OTAVA facilities. The measurement testing was done in an OTA chamber [FIGURE 4]. The OTA chamber is an anechoic chamber lined with RF absorbers. For moving the DUT inside the chamber, a DUT Rotator is placed with +/- 180 degree of movement of azimuth and tilt range. The rotator system has a pole for the DUT mounting. On the other side of the chamber there is also an Antenna Positioner equipped with a Vivaldi antenna which is connected to an oscilloscope. The Antenna Positioner has three axes of movement: antenna height, measurement distance and antenna polarization which rotates the Vivaldi antenna. Outside of the test environment is a control box that controls both positioners, which can be controlled real-time through REST API.

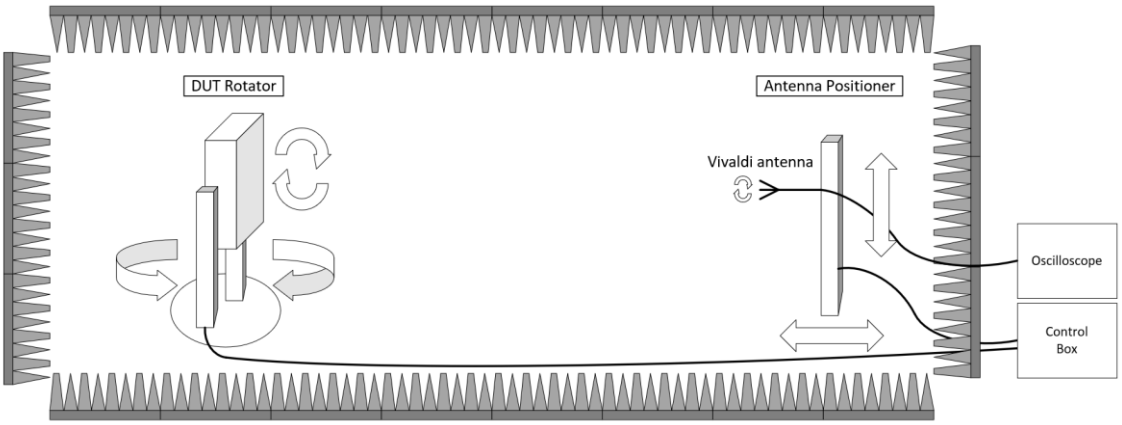

FIGURE 4. The test environment: OTA chamber

Test automation is used to run test cases in the test environment. The test automation is managing the control box and the DUT. With the automated test environment, the tester can repeatably test different DUTs and get comparable test results between each. The main target of the test automation is to enhance productivity of testing by speeding up testing of different DUTs and improving the quality and repeatability.

3.2 Testing Process with the Current Test Case

The current test case is started by using the test automation. The test automation is started with Nokia's internal test runner application. With the application, the tester can choose different test cases and input optional parameters, e.g., how wide a desired measurement is in degrees for azimuth and elevation levels. When the required parameters are given, the application will start the measurement. For this thesis a heat map test case measurement is made to measure 5G NR synchronization signal block (SSB) beams. The heat map measurement is done by scanning the DUT by tilting and rotating the DUT rotator [FIGURE 5]. A so called snake scan method is used to effectively move the DUT Rotator as little as possible, meaning that time used to move between measurement points is as small as possible to minimize the test run time. The snake scan starts processing the top row from left to right, then the second row from right to left, and the third row from left to right, and so on [FIGURE 6]. Elevation positions are changed by tilting the DUT Rotator and horizontal positions by rotating it. For each position a RF power measurement is made and displayed in a current grid, also a heat color is given to visualize the grid's power levels [FIGURE 7].

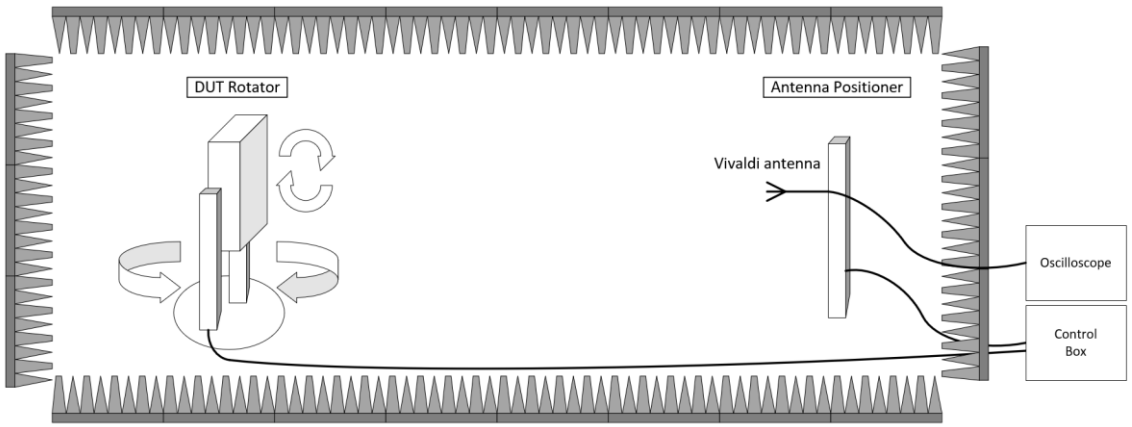

FIGURE 5. The current test case: testing done by tilting and rotating the DUT Rotator and the Antenna Positioner is not moved.

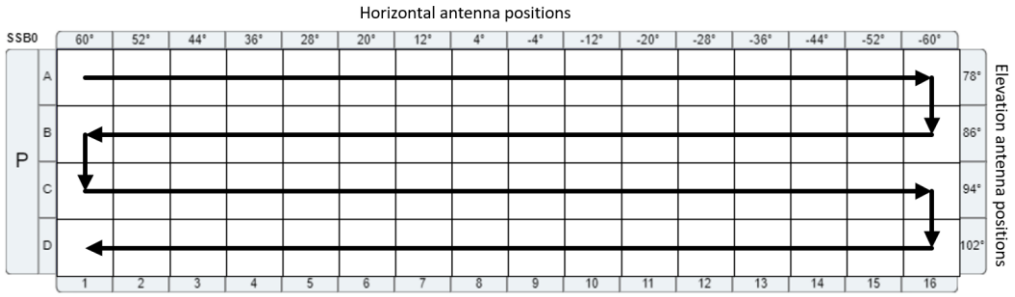

FIGURE 6. Snake scan method

3.3 Results with Current Test Case

Using the current test case, it is not possible to achieve results that are fully comparable with simulated results which are created for each DUT. Figure 6 presents SSB 0 beam's main lobe in red when the current test case is used. The main lobe of the SSB is slightly forming downwards when measurements are taken away from the center of the heatmap and the side lobe shapes are also forming in a way which are not comparable with the simulation results. There are two main factors for this: change of distance between the measuring antenna and the DUT when the DUT Rotator is moved, and combination of tilt and rotation.

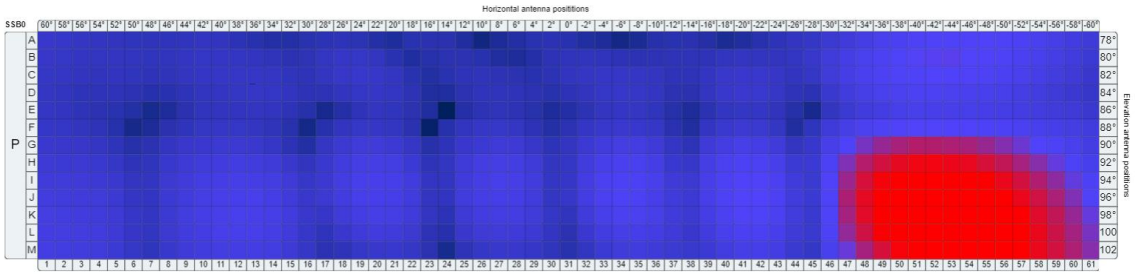

FIGURE 7. The heat map test result of SSB 0 beam using current test method.

3.3.1 Change of Distance Between the DUT and the Measuring Antenna

The first issue to be improved is when the Antenna Positioner is not moved during the current test, tilting, and rotating the DUT Rotator will create change of distances between the DUT's antenna panel and the measuring antenna. This is because the DUT Rotator's tilt and rotation axes are not at the same level as the DUT antenna panel's axes. The axes of the DUT refer to the center of the antenna panel. The pole of the DUT rotator is too close to Rotator's own axes, so it physically prevents the antenna panel to be placed to the same axes. Figure 8 demonstrates this problem where it shows the DUT Rotator and the DUT attached to it. The axes are presented in different colors. The distance between both axes is represented as a DUT depth.

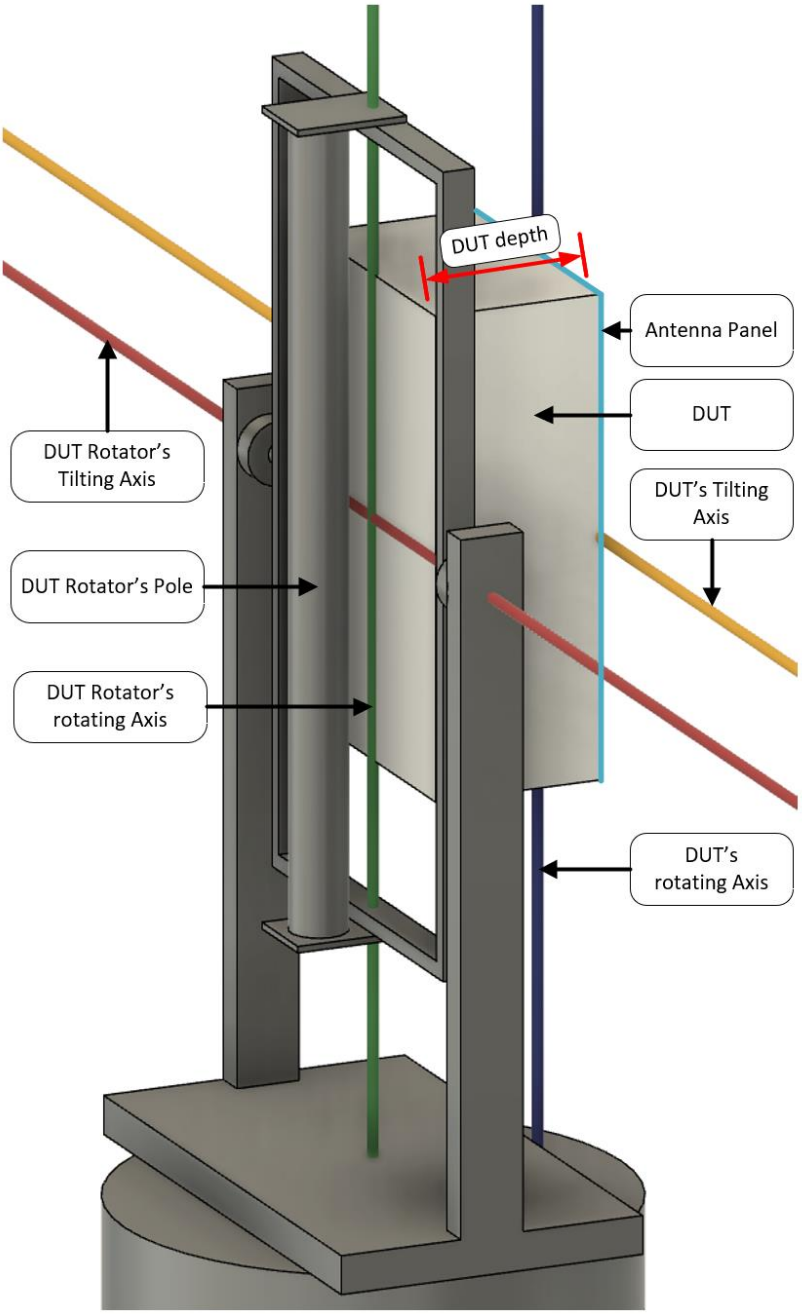

FIGURE 8. Different axes between the DUT and the DUT Rotator

For the current heat map measuring test case the elevation rows are described as the elevation angle which the DUT's antenna panel is pointed to the measuring antenna. Due to the differences between two axes, when the DUT Rotator is tilted the angle of the antenna plane will not match between the measuring antenna. Considering the situation in which figure 9 illustrating this issue in example where angle α from the DUT Rotator is tilted 6 degrees and β is the angle between the antenna panel and the measuring antenna. This error will cause wrong measurements results due wrong alignment of the antenna. The same error also happens when the DUT is rotated.

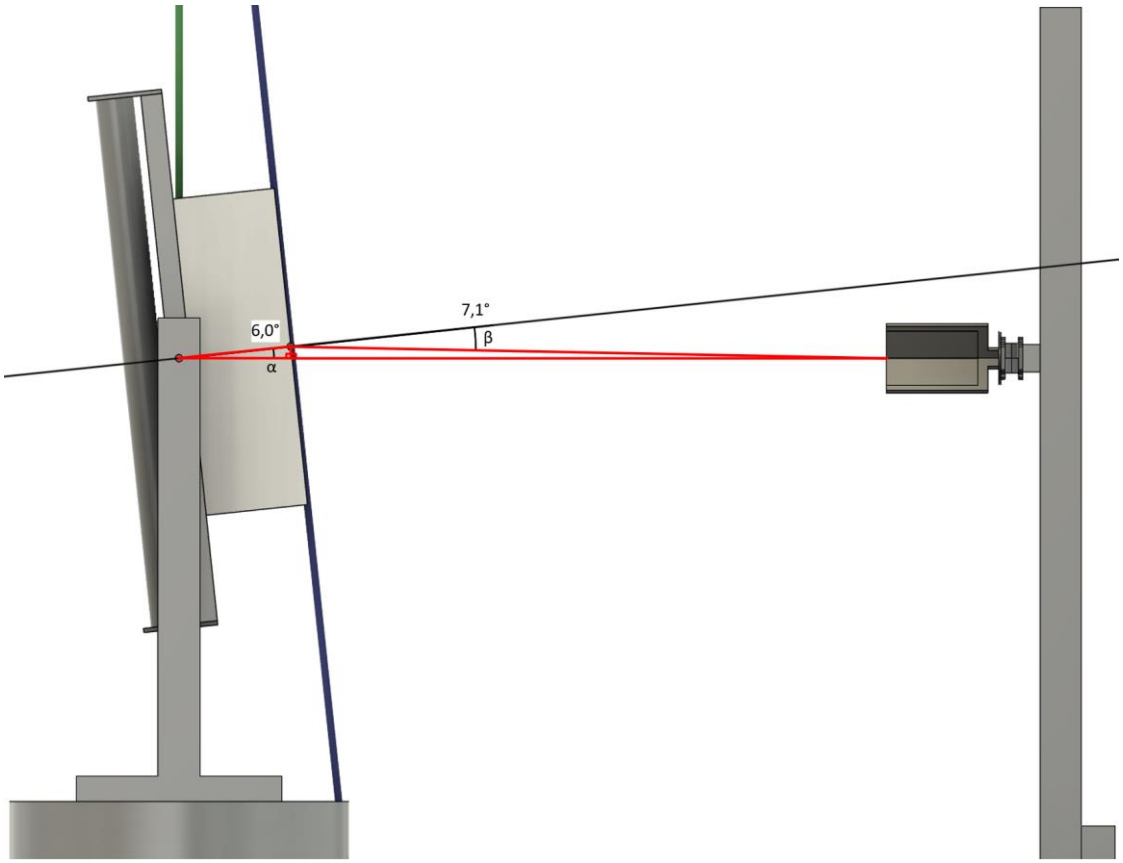

FIGURE 9. Tilt error angle

During the DUT Rotator's rotation, the center point of the DUT's antenna panel cannot rotate around the nominal axis due to the same geometrical issue. Therefore, the DUT's antenna panel center rotates around the axis with geometrical deviation to the nominal axis and the distance between the antenna panel and the measuring antenna will change. Figures 10 and 11 presents the radial variation after 60-degree rotation with axis offset, where in figure 10 the DUT radius illustrates a distance between the antenna panel and the measuring antenna when both are facing each other, and in figure 11 an additional air gap when the DUT Rotator is rotated.

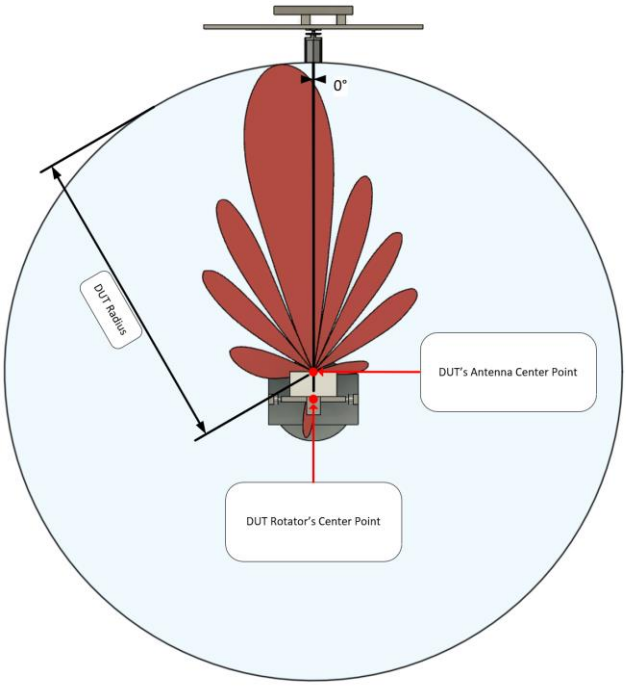

FIGURE 10. Top view. The DUT Rotator pointed to the measuring antenna

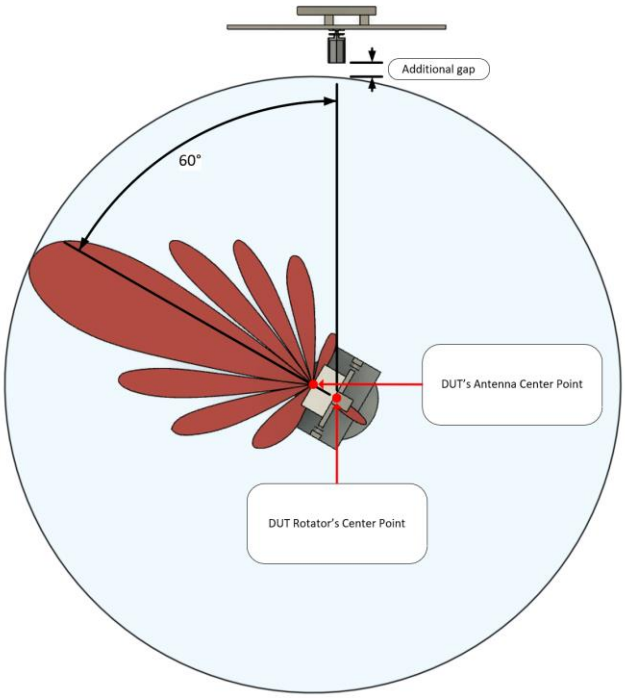

FIGURE 11. Top view. The DUT Rotator rotated 60-degrees

3.3.2 Combination of Tilt and Rotation

The second issue to be improved is when using tilt for measuring different elevation rows for the heat map measurements creates a problem when the DUT is being rotated. For elevation measurements it is important to keep the desired elevation row during horizontal sweep. Because tilt is used to measure the elevation, when the DUT Rotator rotates, the elevation row will change. Figures 12 and 13 demonstrates this problem where a SSB beam is measured. In this situation the SSB beam is pointing 6 degrees down perpendicular to the antenna panel. In figure 12 the DUT Rotator is tilted 6 degrees up to measure the SSB beam in a 96-degree elevation row. The beam is almost perfectly pointing to the measuring antenna but considering previously pointed angle error problem the DUT is tilted a bit too high. Figure 13 demonstrates the effect of rotation, where the DUT Rotator is rotated 180 degrees. In both figures a green dotted line is demonstrating the desired 96-degree elevation row, and it shows that in figure 13 the actual measuring point is far off from where the desired measuring point is. It even measures back lobe of the main beam. Figure 14 shows approximately what points are being measured during the 120-degree horizontally wide heat map test run compared to the planned measuring points, when tilt is used. The figure shows how the actual measuring points start to curve gradually to a 84-degree elevation row.

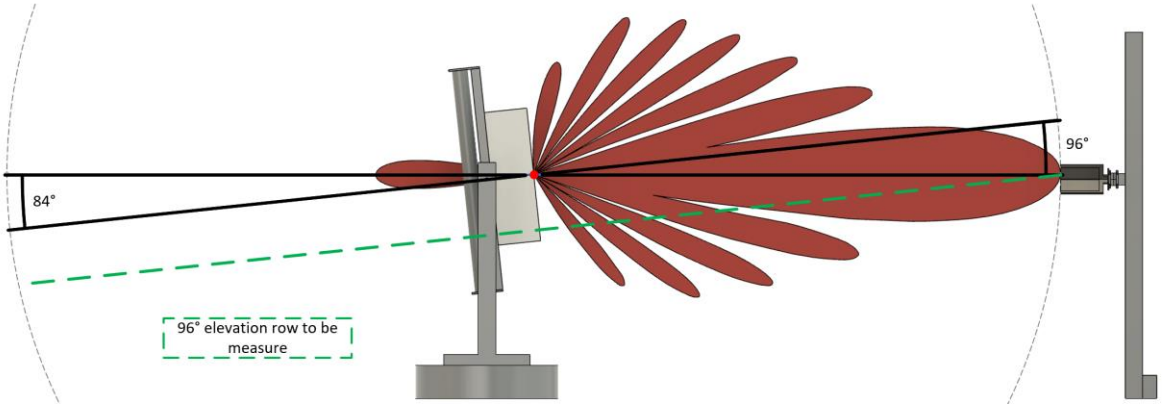

FIGURE 12. DUT Positioner pointed at the measuring antenna with 6-degree of tilt

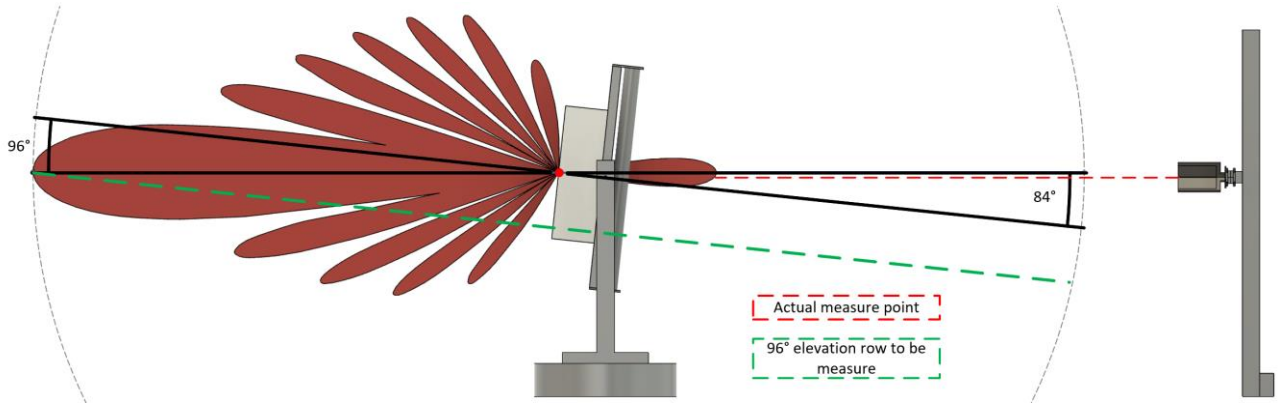

FIGURE 13. DUT Positioner rotated 180-degree with 6-degree of tilt

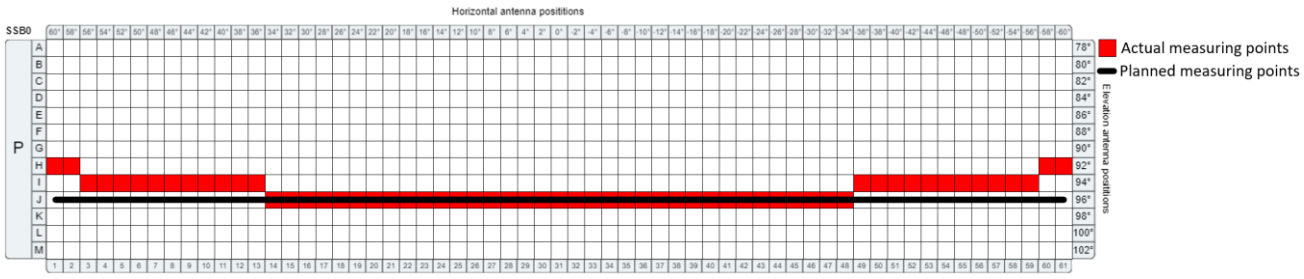

FIGURE 14. Approximate measuring pattern when measuring 96-degree elevation row when using tilt.

4 NEW TEST CASE DESIGN

A different approach is needed to better measure 5G beamforming with the current test environment. A test case design is needed. it considers the changes in angles and distances between the DUT and the measuring antenna as the DUT Rotator rotates. It also needs to accurately measure right elevation and horizontal rows for the heat map measurement.

For modeling the test environment, Autodesk Fusion 360 was used for 3D modeling. Fusion 360 is a cloud-based 3D modeling, CAD, CAM and PCB software platform and it has all the tools necessary for making 3D model and mechanical design for the test environment. The purpose of this test environment modeling is to better understand the limitations of the test environment when moving the DUT Positioner and the Antenna Positioner in the environment. Also designing test cases with full 3D model is much easier in 2D model.

The target of this design is to make a test case, which does not use DUT Rotator's tilt axis to measure elevation angles. Instead, it uses the Antenna Positioner's heigh and distance axes to measure the elevation angle [FIGURE 15]. The angle error between the antenna plane and the measuring antenna is corrected by calculating the correct angle based on the DUT depth and the DUT radius. The distance change is also compensated with this, where the Antenna Positioner's distance axis is used to keep the correct radius during rotation.

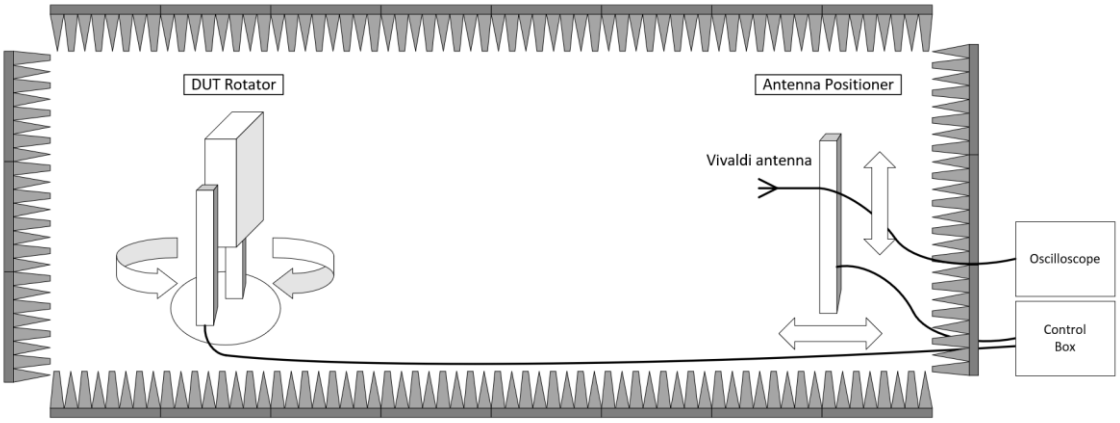

FIGURE 15. The new test case: testing done by rotating the DUT Rotator and the Antenna Positioner is moved in heigh and distance axis.

5 TESTING WITH NEW TEST CASE

5.1 Testing Process

The new test case is started with the test runner application. The starting process is almost the same as the older test case, but the tester needs to input two additional parameters: the DUT depth and the DUT radius. With these values the test automation can calculate correct positions for the DUT Rotator and the Antenna Positioner during the test run. With the radius of the DUT, the plan is to calculate circular test points where the measuring antenna is positioned according to the elevation angles. This will create layers of test points around the DUT's antenna panel. Figures 16, 17 and 18 visualize this by showing orange lines as calculated test points. In figure 16 a blue circle is showing an example where it represents the 96-degree elevation row. A black circle around the middle shows the 90-degree elevation row. In the figure the Antenna Positioner's height is adjusted to place the measuring antenna to the blue circle. Based on the DUT depth value the automation can calculate how the center point of the antenna panel is moving around related to the DUT Rotator's center point. With this the Antenna Positioner can be moved in depth vice to meet the right distance to the antenna panel which is the DUT radius. Figures 17 and 18 are showing the depth adjustment of the Antenna Positioner when the DUT Rotator is rotated from 0-degrees to 180-degrees.

The snake scan method is used again to measure the heat map. The different horizontal positions are now measured by changing the Antenna Positioner's height instead of tilting the DUT Rotator. The horizontal positions are still measured by rotating the DUT Rotator.

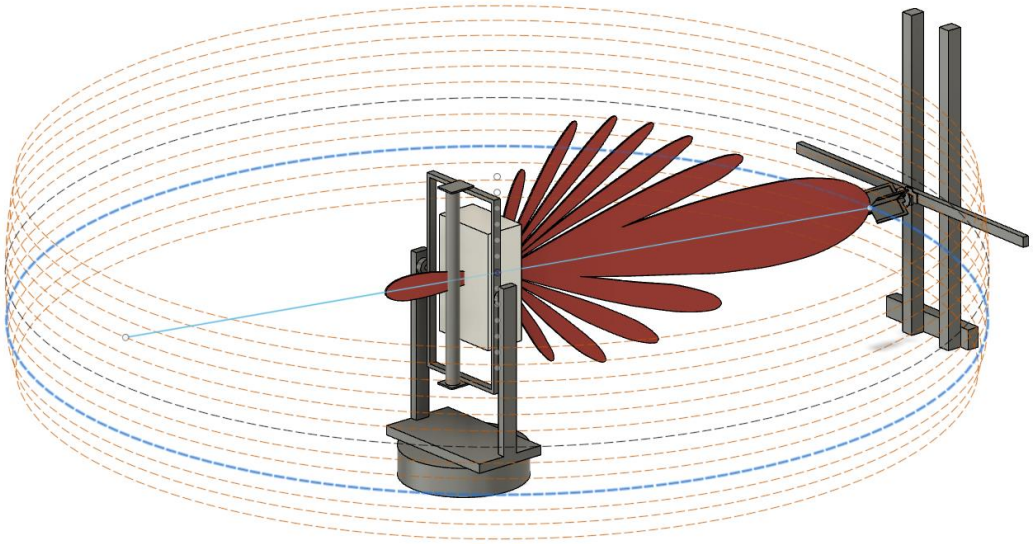

FIGURE 16. Visualized test points

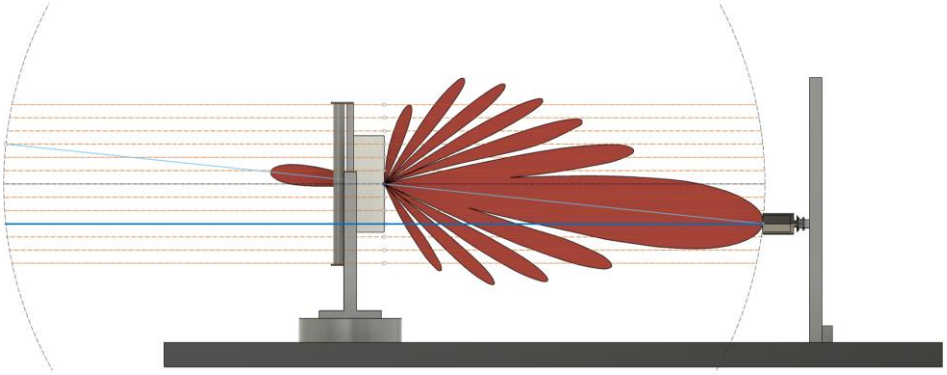

FIGURE 17. Antenna Positioner pointing at 96-degree elevation row

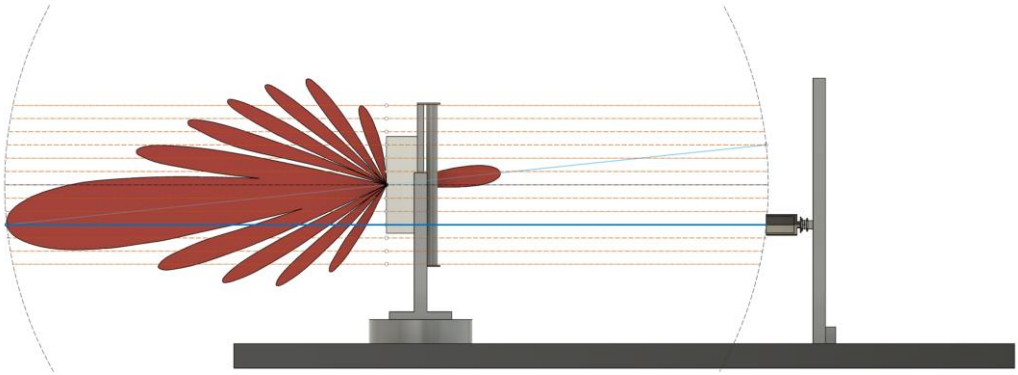

FIGURE 18. DUT Positioner rotated 180-degrees

5.2 Results with New Test Case

Based on the heat map measurement results were successful [FIGURE 19]. Compared to the previous test case results the new test results showed improvements when compared to the simulated result. Especially, side lobes were much better matching the simulated results than the previous test case result. In figure 20, both previous and newest test case results are visualized in a linear horizontal view. The blue line shows the newest test case result, and the orange line shows the previous test case result. In the horizontal view, side lobes from the new test case are far more correctly shaped, where every side lobe is having its own shape, rather than the previous test case's side lobes.

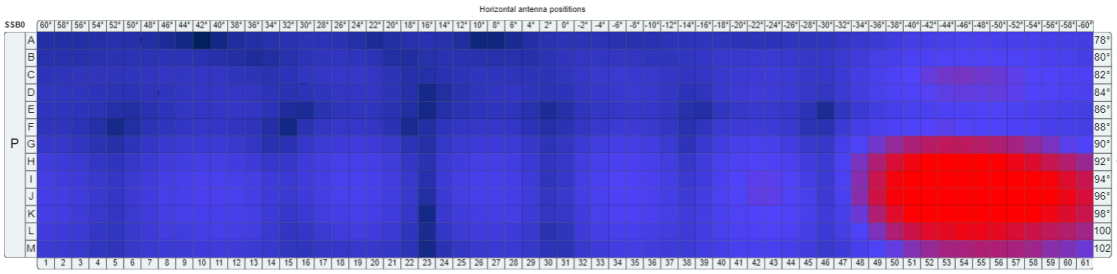

FIGURE 19. Heat map measurement result with the new test case

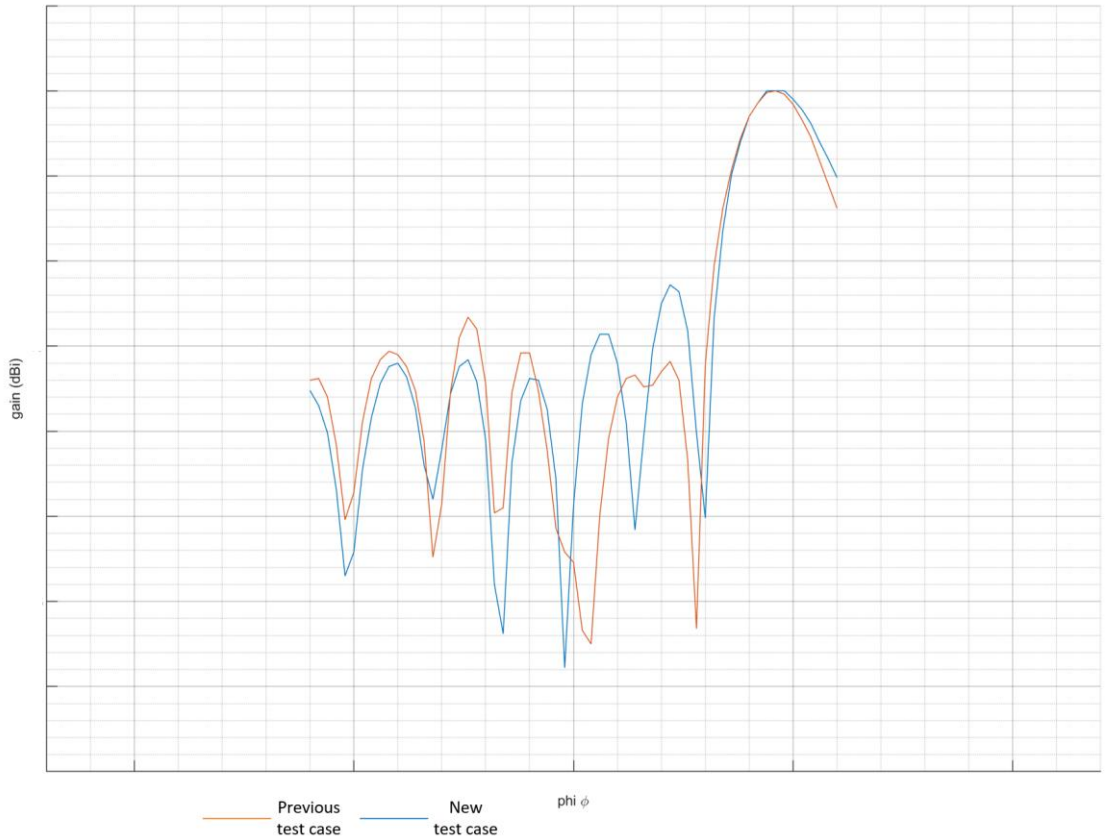

FIGURE 20. Horizontal measurement results from both test cases

6 CONCLUSION

The aim of this thesis was to understand factors which were creating measurement errors during 5G beamforming measurements when using Nokia's OTA chambers and create a new test case to measure them with error factors in mind. Necessary documents, a test case, and measurement reports were created, they are Nokia's internal documents and are not included in this thesis.

The new test case was developed during the thesis, but it was still under development while writing this thesis. The tester can start the test and monitor the test results, but it requires the tester additional knowledge where to add additional information into. The new test case is lacking any sufficient initialization in the test automation for the Antenna Positioner which would move the Positioner to starting position and return it to the default position after the test is done. If some other test case would be started, the Antenna Positioner would sometimes be at wrong place and ruin the other test case's results. So, additional development is needed for a more user-friendly interface to add needed parameters for the test case and initializations for the Antenna Positioner.

The study process to find out what is causing the measurement errors and how to solve them was reasonably challenging. At the beginning the development 2D vector graphic application was used to provide visualization for the geometrical errors, and for the test case planning purposes. This was found to be a poor application for this purpose, because problems to solve were three dimensional and 2D images were not good enough for the study. For the further development Fusion 360 was chosen, because the author had previous experience on that software. After switching to the Fusion 360, it was much easier to continue development of the new test case, because planning and reviewing in 3D environment was possible.

This thesis work can be considered a success. Overall, this thesis was for the author a huge learning experience in OTA testing and the new test case will be further develop.

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