# 5GAFIANCE – Antenas 5G para acceso fijo a Internet con mejora de capacidad

## *5G antennas for fixed Internet access with capacity enhancement*

# E9 – PLAN DE PRUEBAS

## *D9 – Test Plan*

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| PARTICIPANTS | |
|---|---|
| **Participant** | **Name** |
| Nokia | Alfonso Fernández Durán |
| Nokia | Aarón Garrido |
| UC3M | Eva Rajo Iglesias |
| UC3M | José Manuel Poyanco |
| | |
| | |
| | |
| | |

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# 3 Executive Summary

This document describes the measurement plan for the designed antennas, that is, the millimeter-wave reflector antenna fed by a phased array patch antenna at 28 GHz, with a patch antennas conformal to the reflector surface, covering sub-6 GHz frequency bands. The measurement plan described here includes a general explanation of the measurements to be made, together with a specific list of them, considering how the measurement will be carried out, what will be measured, and what results are expected.

In addition, the measurement plan described here includes a general explanation of the measurements to be made, along with a specific list of them, including how the measurement will be carried out, what will be measured, and what results are expected.

In addition, this document describes the measurement plan to be carried out for the characterization of the channel, including the locations chosen for the measurements, plans, antenna positioning, among other characteristics.

# 4 Resumen Ejecutivo

Este documento describe el plan de mediciones para las antenas diseñadas, es decir, la antena reflectora de ondas milimétricas alimentada por un arreglo de antenas phased array funcionando a 28 GHz, con antenas parches conformes a la superficie del reflector, que cubren bandas de frecuencias sub-6 GHz. Las mediciones aquí descritas incluyen una explicación general de las medidas a realizar, junto con un listado específico de ellas, considerando cómo se realizarán las mediciones, qué se medirá y qué resultados se esperan.

# 5 Introduction

Technological needs in general have led to the new communication systems having the characteristic of increasingly wider bandwidths. For this reason, it has been necessary to increase the operating frequencies in order to increase the data transfer rate. The main problem with using higher frequencies, e.g. millimeter wave bands, is that propagation losses increase along with the frequency.

To counteract the increase in propagation losses, it is necessary to use more directive antennas, such as lens antennas, patch antenna arrays and/or reflectors.

For a correct functioning of antennas operating at these high frequencies, it is necessary to study how they propagate in the propagation channel, in order to obtain a good communication link.

Even though these new communication systems are aiming at higher frequencies, communication at lower frequencies is still relevant. Therefore, a solution has been presented to use both frequencies in parallel, without increasing the total volume of the initial antenna.

This solution consists of a parabolic antenna fed by a phased array patch antenna, operating within the millimeter wave. It is proposed that on the reflector surface, it is possible to position patch antennas operating at sub-6 GHz frequencies, without significantly impacting the millimeter-wave operation, as long as the substrate of the patch antennas has a certain thickness.

These antennas have already been designed, so this document presents the test plan to be performed, including a detailed explanation of each one of them. In addition, a channel characterization test plan is detailed, using commercial antennas and the reflector with conformal patches.

# 6 Test plan.

## 6.1 Test plan for the designed antennas

To study the performance of the designed antennas, two different kinds of measurements will be done:

- Measurement with the vector network analyzer (VNA, Fig. 1) of one and two ports:

  With this device, it is planned to study the matching of the antennas ($S_{11}$). Generally, a matching value lower than -10dB for the design frequency is considered a well-matched antenna. These values may change depending on the intended use of the designed antenna. This is a one port measurement.

  In addition, it is necessary to know the coupling between ports, in order to study the diversity. In general, a coupling value lower than -15dB is considered good, but for this particular work, lower values are expected for a capacity improvement. In this case two port are needed ($S_{12}$).

  This measurement will be performed on the prototype of the phased array patch antennas with the different feed networks with different designed phase shift; and on the conformal patch antennas designed to operate in the sub-6 GHz band.


*Fig. 1 Vector network analyzer (VNA) R&S ZVB40 available for measurements. [1]*

- Anechoic chamber measurement (Fig. 2):

  With these measurements it is planned to measure the gains of the designed antennas, as well as their far field radiation pattern if required, in two planes (E-plane and H-plane) for each port, for each frequency studied.

In addition, it is expected to measure the cross-polarization level to study the amount of energy that is received by the polarization orthogonal to the emitted signal.

This measurement will be carried out on the prototype phased array patch antennas with the different feeding networks by itself and being used as reflector feed, to study the different pointing angles achieved.

On the other hand, this measurement will be performed on the reflector conformal patches.

In addition, a measurement of the reflector with its feed with and without the conformal patches will be made to study the effect caused by the patches.

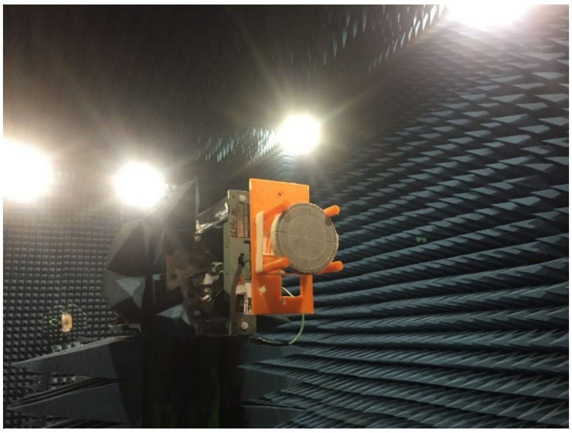

*Fig. 2 Anechoic chamber. Reference image.*

Below is a list of the measures to be carried out.

- Reflection coefficient ($S_{11}$) for the conformal patches, at each port.

  This measurement is performed to know the matching of each of the antennas in the frequency bands b40 and b42, that is, the ratio of the reflected power to the transmitted power for each antenna, for the frequency range analyzed. For this, a sweep will be performed between 1 and 5 GHz to include both bands. The VNA will be used, using a coaxial cable connected on one side to the VNA and on the other side to the antenna port. This is repeated for the other port. It is expected that, in the frequency ranges of interest (b40 and b42 band), the values will be less than -10 dB, in order to confirm that most of the energy is being radiated.

- Reflection coefficient ($S_{11}$) for phased array patch antennas.

  This measurement is carried out to study the matching of the phased array patch antennas. In this measurement, the frequency of interest is 28 GHz, but a sweep will be made between 26 and 30 GHz in order to study a wider band. As in the previous measurement, the VNA will be used, employing a coaxial cable connected to the antenna port and, on the other side, connected to the VNA.
  It is expected that for the frequency range studied, the values will be less than -10 dB, to confirm that most of the energy is being radiated and not reflected.

- Transmission coefficient ($S_{12}$) between ports of the conformal patches.

  The transmission coefficient is a parameter that relates how much energy sent by one port is received at the other.
  Since the frequency bands of interest for the conformal patches are b40 and b42, a frequency sweep between 1 and 5 GHz will be performed to include both bands in one measurement.
  The device used for this measurement is the VNA. It is necessary to connect each of the ports of the conformal patches to two different ports of the VNA simultaneously.
  The transmission coefficient values in the bands of interest are expected to be lower than -15 dB to confirm that they are sufficiently isolated from each other to have an improvement in channel capacity.

- Gain versus frequency for the phased array patch antennas.

  The gain of an antenna is the amount of power that is transmitted in the direction of maximum radiation relative to that of an isotropic source. This is measured inside an anechoic chamber. The antenna under test (AUT) and a reference antenna are positioned inside it, measuring the transmission coefficient between them to then calculate the gain value.
  Although phased array patch antennas are designed to operate at 28 GHz, these measurements will be made between 26 and 30 GHz, the same frequency band as for the reflection coefficient.
  Lower values but close to 10 dBi are expected, which the values wereobtained by simulation, due to the inclusion of losses and prototyping and assembly errors.

- Gain versus frequency for the reflector without conformal patches.

  The gain will be measured for the frequency range between 26 and 30 GHz, which contains the operating frequency of the reflector, that is, 28 GHz.
  This measurement will be carried out inside an anechoic chamber, positioning the antenna under test, that is, the reflector fed by phased array patch antennas, in front of a reference antenna. This measurement is made to later study the differences by including the conformal patches.
  The expected values are around 25 dBi, which were previously obtained by simulation.

- Gain versus frequency for the reflector with conformal patches.

  This measurement is made for the same frequency range as the previous measurement, that is, between 26 and 30 GHz, inside an anechoic chamber. The difference with the previous measure is that this time the conforming patches are included. With this measurement and the previous one we will be able to quantify the gain drop when including these conforming patches.
  A gain drop of -2 dB is expected, so the values will be around 23 dBi for the central frequency.

- Far-field radiation pattern for the reflector with conformal patches in the E and H planes.

  The far field radiation pattern is a measure of gain for each angle of the antenna. This is measured inside an anechoic chamber, by positioning the antenna under test (AUT), in this case the reflector fed by phased array patch antennas, facing a reference antenna. The difference with the previous measurement is that the AUT is rotated on its own axis perpendicular to the floor, in order to measure the gain values for each angle.
  To be consistent with the study, the radiation pattern will be measured for 26, 27, 28, 29 and 30 GHz, that is, in the frequency band of interest, with steps of 1 GHz.
  The measured radiation pattern is expected to have a brush beam shape, with a slight increase in the lateral lobes due to the inclusion of conformal patches. Even so, it is expected that the ability to focus the energy is the same, that is, that the width of the main beam is the same.

- Cross-polarized far-field radiation pattern.

  The radiation pattern with cross polarization is measured exactly as the radiation pattern in the far field explained above, with the difference that this time the reference antenna has a polarization orthogonal to that of the antenna under test, in order to quantify how much energy radiates the antenna under test with orthogonal polarization.
  When you have an antenna with perfectly ideal polarization, this value is very low, but the practical values achievable are between -15 and -20 dBi for the main beam, which are the expected values for this measurement.

## 6.2 Test plan channel measuring mechanism

The first time a user equipment is installed, it is necessary to locate the direction of maximum power to point the receiving antenna. Or even, channel changes may occur, or the user equipment may change orientation or location. So, it is necessary to perform a scan to locate the directions of maximum power, because with millimeter wavelengths occurs a shadowing produced by the walls and even windows of a house, as more objects become comparable with the wavelength.

For this reason, general conditions are sought to speed up the scanning process, as it is temporarily costly to scan all angles every time that there are changes in antenna conditions.

For example, suppose a scan is required every one degree, in all directions. If the measurement takes one second for each position, it will take eighteen hours to perform the entire scan, which makes it impractical. Let's assume another more optimistic scenario in which only half of the angles are required to be measured and the measurement takes a quarter of the time at each point. It would still take wo and a quarter hours for this exercise.

Therefore, it is planned to perform measurement campaigns in indoor-indoor and indoor-outdoor scenarios, with the intention of characterize these scenarios in order to try to generate some initial conditions for the scanning of the user equipment.

This task will be performed using the automatic mechanical scanning system presented previously [2]. First, commercial horn antennas covering the Ka-band will be used. Subsequently, it is planned to perform these measurements with the designed solution antenna, that is, the reflector antenna with conformal patches. With this designed antenna, it is planned to perform measurements both for the millimeter frequencies and for the sub-6 GHz band.

The measurements will be made by obtaining the transmission parameter between two antennas (S12). With this parameter, a comparison between the different relative received power levels can be made to study the power differences as the receiving antenna is rotated.

It is expected that the highest value of relative received power will occur when the antennas are facing each other, either with direct line of sight (LOS) or with some intermediate obstacle, such as glass.

In cases where there is no LOS, the direction of maximum relative power is expected to occur in the directions of a single bounce.

### 6.2.1 Indoor-Indoor scenario

As a representative scenario of an indoor-outdoor channel, an area of the UC3M was chosen. For these measurements, transmitter and receiver antennas will have the same height. Fig. 3 show the plan of this scenario.

Ten different positions have been chosen for the receiving antenna and two positions for the transmitting antenna, evenly distributed over the surface. It is important to say that the receiving antenna, the one on the tripod, is the one that has the capacity to rotate, that is to say, it has the mechanical pointing system.

The measurement setup is shown in Fig. 4**¡Error! No se encuentra el origen de la referencia.**. One of these antennas will be positioned on a camera stand, allowing the height to be calibrated if necessary. On the other hand, the second antenna will be on a non-variable height stand, so the first antenna will be adjusted to the same heigh.

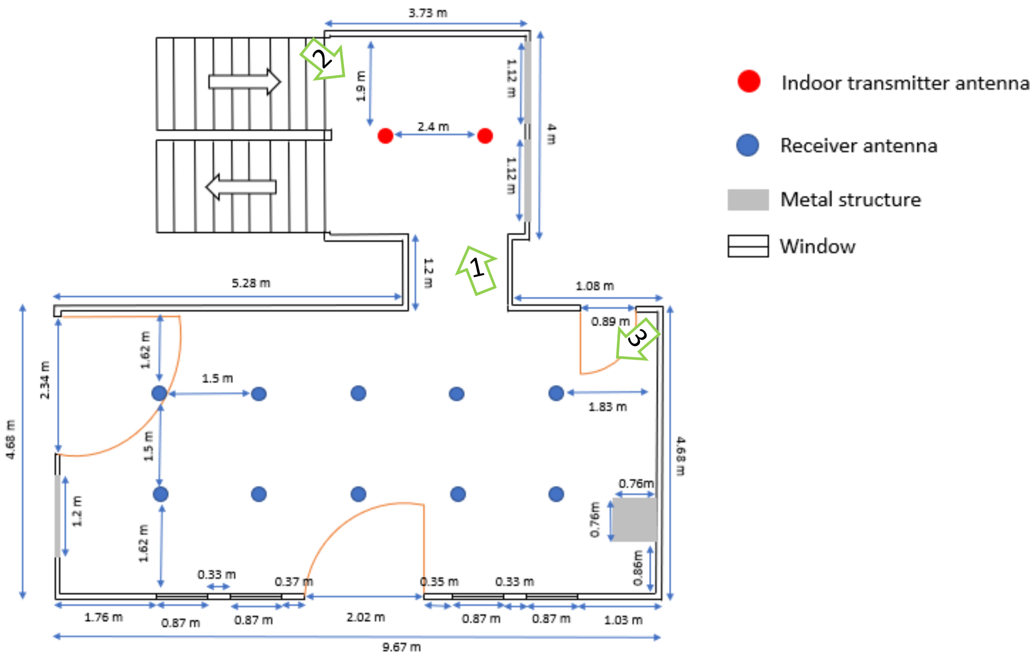


*Fig. 3 Selected area plan for indoor-indoor measurements.*

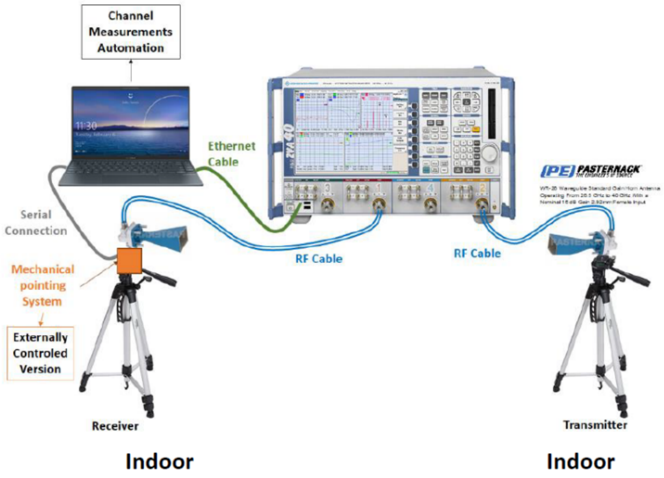


*Fig. 4 Indoor-indoor measurement setup.*

For these indoor-indoor measurements, the fixed antenna shall be placed 80 cm above the ground. For that reason, the tripod is fixed at that same heigh.

If we select one degree of step in azimuthal and elevation, is very time consuming to measure all the 32400 positions (360° azimuthal position x 180° elevation positions). For this reason, the measures will be done with ten degrees elevation and azimuthal steps, having 648 measures ((360°/10) * (180°/10)) of the half sphere, as shown Fig. 5.

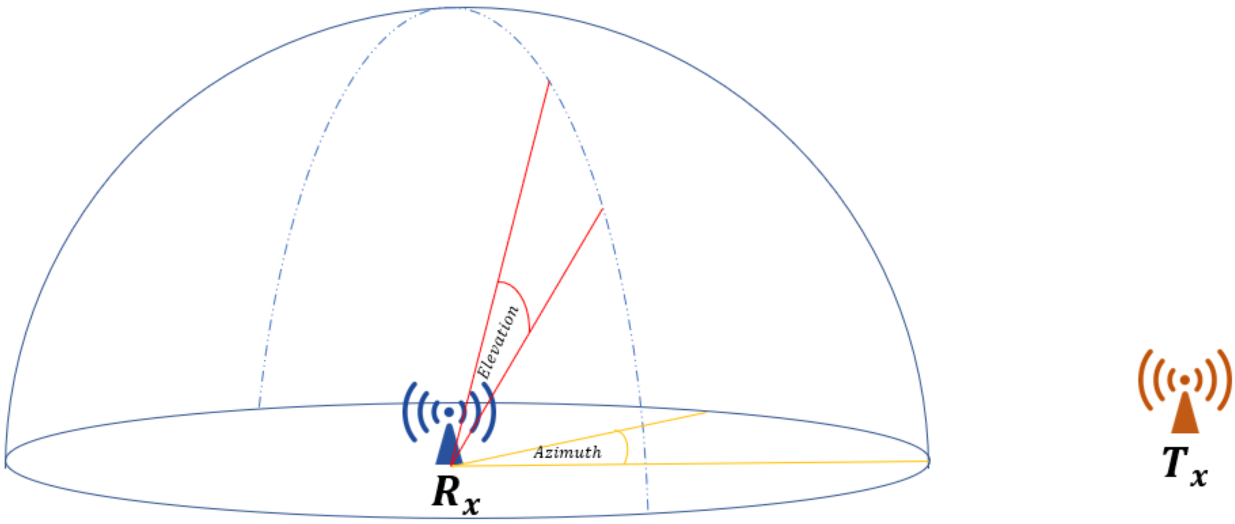


*Fig. 5 Half-sphere measurement .*

### 6.2.2 Indoor-outdoor scenario.

For this type of scenario, an area adjacent to the previous one was chosen, using the same positions for the rotational antenna. The plan for these measurements is shown in Fig. 8, which also shows where the transmitting antenna will be positioned. The measurement diagram is shown in Fig. 7.

Two types of measurements are planned for this scenario. The first will be made with the antenna heights the same as the previous one, i.e., 80 cm height for both antennas. In the second set of measurements, the transmitting and receiving antenna will have different heights, to simulate the scenario shown in Fig. 6a. The transmitting antenna will have a total height of 2.51 m and the receiving antenna will have a height of 0.8 m, making a triangle equivalent to the reference, shown in Fig. 6b, equivalent to the theoretical one. The reason for selecting this height is that the maximum cable lengths available were taken into consideration.

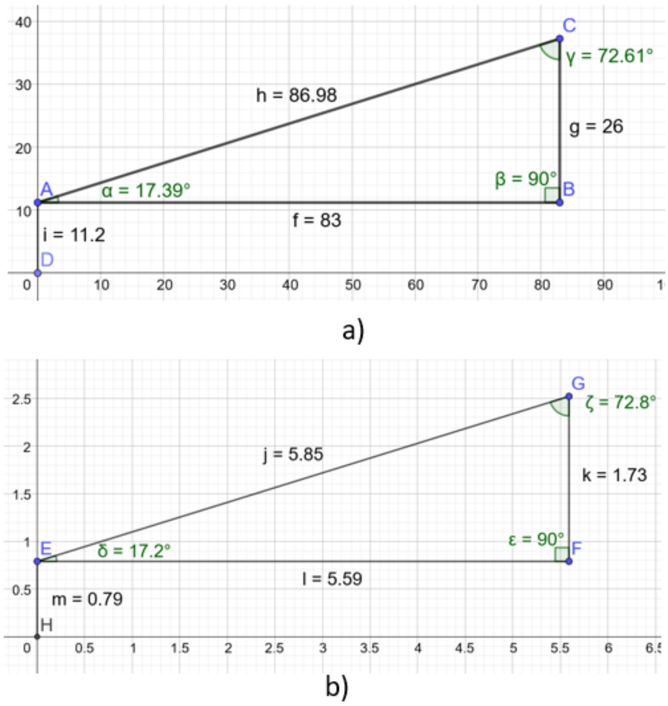


*Fig. 6 Triangles of height and angles of antennas. a) Theoretical case. b) Implementation plan.*

It is important to say that for these measurements, the azimuthal and elevation steps will be the same than the previous scenario, that is, steps of ten degrees for azimuthal and elevation (Fig. 5 reference)

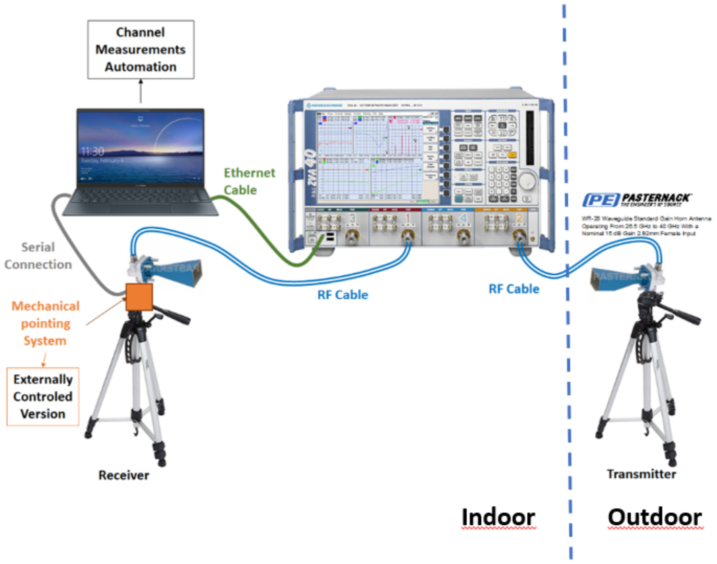


*Fig. 7 Indoor-outdoor measurement setup diagram.*

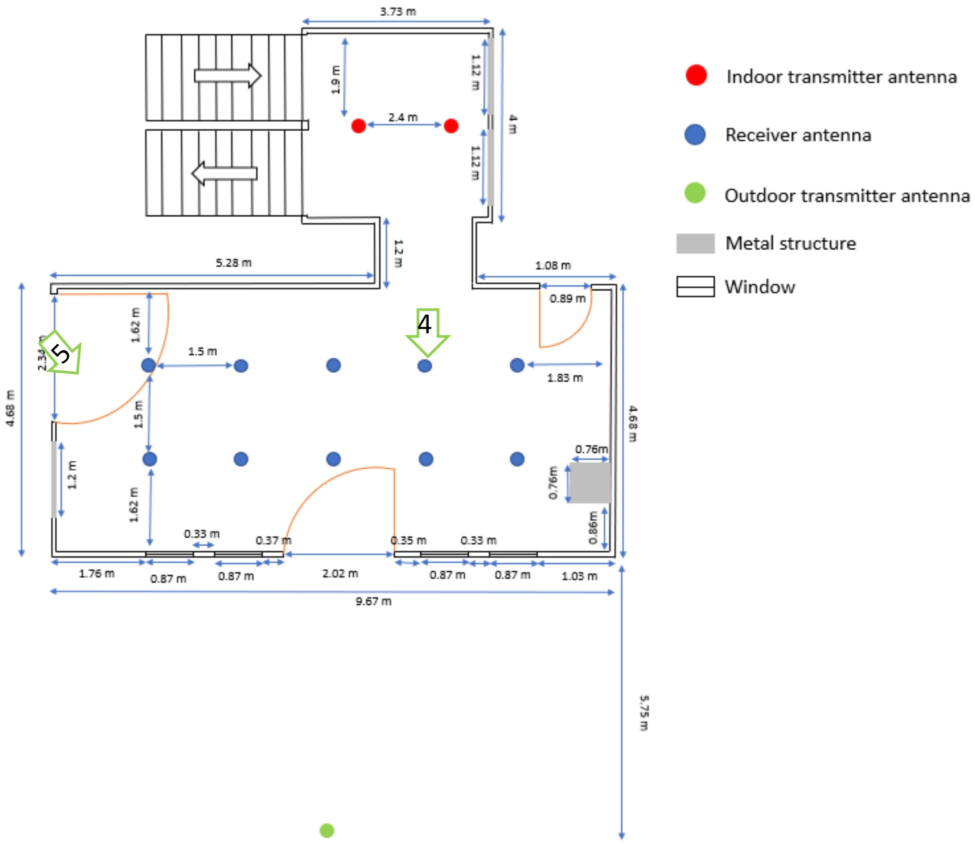


*Fig. 8 First indoor-outdoor measurement scenario plan.*

In order to better analyze the behavior of the millimeter waves in indoor-outdoor conditions, measurements were performed in a second scenario. The plan of the chosen area is shown in the Fig. 9.

In this second scenario, the transmitting antenna will be positioned outdoors, and the rotating receiving antenna will be positioned in six different locations homogeneously distributed over the indoor surface, as shown in Fig. 9.

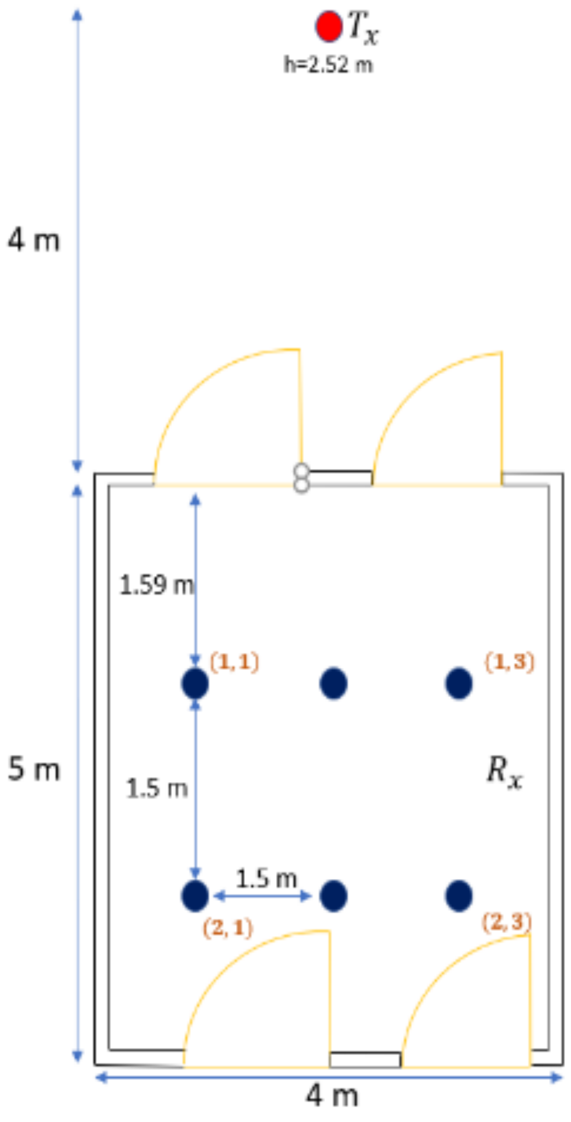


*Fig. 9 Second indoor-outdoor measurement scenario plan.*

Below are photos of the selected locations where the measurement program will be carried out.

*Fig. 10 Transmitting antenna positioning room for indoor-indoor measurements. Photo taken from the green arrow number 1 shown in Fig. 3.*

*Fig. 11 Transmitting antenna positioning room for indoor-indoor measurements. Photo taken from the green arrow number 2 shown in Fig. 3.*

*Fig. 12 Receiving antenna positioning room for indoor-indoor and indoor-outdoor measurements. Photo taken from the green arrow number 3 shown in Fig. 3.*

*Fig. 13 Receiving antenna positioning room for indoor-indoor and indoor-outdoor measurements with view to the outdoor area where the transmitting antenna of these measurements will be positioned. Photo taken from the green arrow number 4 shown in Fig. 6.*

*Fig. 14 Receiving antenna positioning room for indoor-indoor and indoor-outdoor measurements with view to the outdoor area where the transmitting antenna of these measurements will be positioned. Photo taken from the green arrow number 5 shown in Fig. 6.*

# 7 Conclusions

This documents shows the different measurement process to study of the prototype of the previously designed antennas. It also shows how the channel measurements will be performed, in order to characterize it with the objective of generate initial values to point the antenna in the direction of maximum power, avoiding scanning in all directions.

For the designed antennas, a total of eight measurements will be performed, using the vector network analyzer (VNA) and/or an anechoic chamber, measuring matching values, energy transfer, and far field radiation pattern.

In addition, the scenarios chosen to perform the channel measurements are shown, representing indoor-indoor and outdoor-indoor scenarios, including photos and explanatory drawings for a complete understanding of the test plan.

# 8 References


[1] ConRes Test Equipment. (2022). Retrieved 10 March 2022, from https://www.conrestestequipment.com

[2] Deliverable D8, "Implementatios and Evaluation of Beam Control Algorithms", 5GAFIANCE project, January 2021.