5G-MiEdge
Millimeter-wave Edge Cloud as an Enabler for 5G Ecosystem
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Abstract
This deliverable reports details related to the development of millimeter-wave antennas and measurement system for 5G enabled stadium as considered in the 2020 Tokyo Olympic use case. Two types of antennas were designed for millimeter wave shower and backhaul link respectively. The compact antenna test range to be used for the measurements of high gain antennas in limited space is described too.

Keywords
millimeter-wave access, millimeter-wave backhaul, millimeter-wave antennas, planer waveguide slot array antenna, compact antenna test range

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## Abbreviations

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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>AAS</td>
<td>Active Antenna System</td>
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<td>AUT</td>
<td>Antenna Under Test</td>
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<td>CATR</td>
<td>Compact Antenna Test Range</td>
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<tr>
<td>CRS</td>
<td>Cell Specific Reference Signal</td>
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<tr>
<td>DDD</td>
<td>Directional Division Duplex</td>
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<tr>
<td>FDD</td>
<td>Frequency Division Duplex</td>
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<tr>
<td>FEM</td>
<td>Finite element method</td>
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<td>FF</td>
<td>Far Field</td>
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<td>FWA</td>
<td>Fixed Wireless Access</td>
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<td>GATE</td>
<td>Gigabit access transponder equipment</td>
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<td>mmWave</td>
<td>Millimeter-wave</td>
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<td>RSRP</td>
<td>Reference Signal Receive Power</td>
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<td>SDR</td>
<td>Software Defined Radio</td>
</tr>
<tr>
<td>TDD</td>
<td>Time Division Duplex</td>
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<tr>
<td>USRP</td>
<td>Universal Software Radio Peripheral</td>
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Executive Summary

This deliverable provides the details of the mmWave antenna prototypes designed within the project for a 5G enabled stadium like the one considered in the 2020 Tokyo Olympic use case. The mmWave antennas play an important role in 5G enabled stadium because they are one of the key components essential to satisfy the very demanding requirements of future 5G communication systems such as high data rate, low latency and massive number of connections.

This deliverable reports design and measurement results for two of the mmWave antennas designed for a 5G enabled stadium: the antenna to be used to realize the “information shower” installed at the gates of the stadium and the antenna to be used for the backhaul link. The antenna destined to the information shower is a passive 32x32 element array antenna operating in the 60 GHz frequency band. Such a kind of antenna is able to provide an adequate radio coverage in a limited area close to the entrance/exit ports of the stadium allowing then the fast download at extremely high bit rate of files related to the events occurring at the stadium. Regarding some of the realized antennas prototypes, the measured gains are, for example, ~44dBi for the 64x64 element array, ~40dBi for the 32x32 element array, ~33dBi for the 16x16 element array. Radiation patterns will be measured after the release of this deliverable using these CATR system described in this deliverable.

The antenna to be used in the backhaul link is a 20x20 element array antenna designed for operation in the 40 GHz frequency band. In order to utilize the frequency resources more efficiently, a Directional Division Duplex is adopted to double the transmission capacity compared to the conventional TDD or FDD. The main characteristics of the backhaul antenna are the following: reflection coefficient ~10dB, gain ~32dBi, side lobe level below -30dB.
1 Introduction

This document focuses on the mmWave antenna prototypes designed for a 5G enabled stadium (i.e., the 2020 Tokyo Olympic use case considered within 5G-MiEdge project). A 5G enabled stadium represents the key building block for the realization of the stadium of the future, a smart environment where it is possible to experience immersive communication, providing to the viewer a dramatically new way to participate to a sport (or others) event. In such an advanced context the mmWave antennas are one of the key components enabling the 5G system to provide extremely high data rates with low delays to a massive number of connections. And the challenge is even higher taking into account that, those connections, have to establish very close to each other. The activities carried out focused on two kind of antennas: those destined to the realization of the information showers to be placed at the stadium entrance and those to be used for the backhaul.

The document is organized in the following way. After the introduction reported in section 1, section 2 and section 3 are dedicated to mmWave antennas for gate system and mmWave antennas for backhaul link respectively. In section 4 is described the CATR to be used for antenna measurements in far field conditions.

1.1 5G enabled stadium

5G enables high data rate, low latency and connection with massive number of devices. 5G enabled stadium offers audiences new wide variety of services [intel]. Possible application of 5G are as follows.
- Replay 4K video distribution [KDDI], [Extreme]
- High speed WiFi connection at audience seats [RAPID]
- Limited distribution of digest video only for audience
- High speed and low latency wireless connection between 4K/8K video camera and data center as shown in Figure 1-1

Figure 1-1: Stands and sports arena.
1.2 2020 Tokyo Olympic

The 2020 Tokyo Olympic represents one of the most challenging use cases of extreme mobile broadband due to both the very high bit rate requirements per single connection and the very high user density. In addition to the requirements affecting the total system capacity, the very low latency required by some of the advanced multimedia services (e.g., immersive communications) makes even more difficult to design an adequate communication system.

These applications will require a combination of ultra-high connection density, high data rate and low latency.

1.2.1 Stadium gates

At the stadium gate shown in Figure 1-2, visitors download specific application of the event and large data (related videos in the past events, player’s profile etc.) to enjoy the unique applications, such as AR/VR, while they are watching the game.

Visitors can also download the 4K/8K premium videos of the game when they leave the stadium, in such a case is assumed that downloaded content size is about 1~5 min. compressed video clip.

1.2.2 Stand and sports arena

At sports events, the videos from multiple 4K/8K video cameras are collected to the edge server, and then multi-viewpoint live videos are created in real-time for TV broadcast. The multi-viewpoint videos are also shared with spectators wirelessly to enjoy 360° high-definition live videos on their smartphone/tablet. The edge server also creates AR/VR videos for the spectators to enjoy unique user experience.

Figure 1-2: 2020 Tokyo Olympic stadium gate scenario.
1.3 Required antenna specification and antenna characterization

In order to realize these applications in 2020 Tokyo Olympic, two different types of antennas are required for mmWave Shower and backhaul link. Required antenna specifications for mmWave Shower are as follows.
- High gain
- High antenna efficiency
- Wide bandwidth
- High uniformity of array excitation

Required antenna specifications for backhaul are as follows.
- High gain
- High efficiency
- Wide bandwidth
- Low sidelobe
- High isolation

In order to characterize such antennas, wide variety of measurement systems are required such as vector network analyzer (measurement of reflection coefficient), far-field measurement system, near-field measurement system and CATR, whose characteristics are reported in this deliverable.
2 mmWave antennas for gate system (mmWave shower)

2.1 Introduction

Figure 2-1 (a) illustrates the 60 GHz-band GATE (Gigabit Access Transponder Equipment) to be equipped as the fixed terminal in public areas such as in corridors and escalators located in stations and departments stores, and at other locations. When a user holding a mobile terminal passes through a GATE, gigabit access is available in its clearly defined coverage area named here as the “compact-range”. In this project, a compact range provides an almost constant field strength and the high speed data transfer of 3.5 ~ 6 Gbps, when it is occupied by only a single-user and downloading is completed in a short time (burst-type). This would enable visual DVD of 6 GB to be downloaded in less than 10 seconds for example. Therefore, the key issue is how to construct a signal reception zone with a width of tens of centimeters and a working distance up to 10 m to realize gigabit access for as long a period as possible.

According to [D1.1], there are six entrances in the 2020 Tokyo Olympic stadium as shown in Figure 1-2 and each entrance has 20 gates. The required data rate for one gate is 1.7 Gbps and 8.6 Gbps for entering and exiting case, respectively. The requirements are summarized in Table 2-1.
2.2 Design and analysis results

2.2.1 Antenna configuration

The circularly-polarized slot array antenna consists of corporate feed waveguide in the lower layer and a radiating part in the upper layer as shown in Figure 2-2 and Figure 2-3. The antenna is fed through an aperture from its backside, and the coupling slot is located at each end of the feeding circuit in order to feed 2x2 exciting slots on a wall-inserted cavity. Finally, a circularly-polarized radiating aperture is fed through the exciting slot. The radiating aperture is square which is trimmed off two diagonal corners for the circular polarization. The radiating apertures are placed with constant spacing in the x and y directions.
Figure 2-2: Circularly-polarized waveguide slot array antenna.

Figure 2-3: Bird's-eye view of the 2x2-element array.
2.2.2 Designing subarray by genetic algorithm (GA)

The 2x2-element array is designed by GA for wider bandwidth. In this document few definitions of bandwidth are introduced. The first one is related to the axial ratio (circular/elliptical polarization): all the frequencies where this ratio is less than 3dB. The second one is related to the reflection coefficient: the frequencies where this value is less than -14dB. The axial ratio depends on the shape of the radiating aperture and the radiating slot, and the reflection depends on all parts in the 2x2-element array. The design procedure is an optimization process that starts using like target the axial ratio, than the reflection coefficient and finally both these variables.

The antenna thickness should be an integral multiple of 0.2mm (plate thickness). The axial ratio is so sensitive to the thickness of the radiating aperture that the thickness varies 0.2mm steps for the axial ratio. The bandwidth for axial ratio maximized for each thickness. Figure 2-4 shows the bandwidth as a function for the aperture thickness. The thickness for the bandwidth more than 16% is a range from 4.6mm to 5.4mm.

The bandwidth for both the axial ratio and the reflection is achieved 14.6% for the thickness of 4.6mm.

![Figure 2-4: Axial ratio bandwidth for the aperture thickness [ISAP14].](image)

2.2.3 Full structure simulation

The 16x16-element array consisting of the designed sub-arrays and the feeding circuit is simulated by HFSS. The axial ratio, directivity gain and realized gain are shown in Figure 2-5. The bandwidth for antenna efficiency more than 80% is 17.2% and that for the axial ratio is 16.6%. The directivity and realized gain decreases rapidly at 61.2 GHz. This is caused by generation of undesired higher order mode of the radiating aperture. To remove the gain decrement, the dimension or the shape of the radiating aperture has to be modified so that the undesired higher order mode does not generate in the bandwidth.
2.3 Experimental results

2.3.1 Fabricated antennas

A total of six types of antennas of different sizes were fabricated by diffusion bonding of thin copper plates: 2×2, 4×4, 8×8, 16×16, 32×32, and 64×64-element arrays [IEEETAP15]. Figure 2-6 is a photograph of these tested antennas. The element spacing for all antennas is 4.2 mm in common. The aperture size for an $N \times N$-element array antenna is defined as $(4.2 \times N) \times (4.2 \times N)$ mm$^2$. The 32×32-element array was fabricated by diffusion bonding of thin aluminum plates as well as shown in Figure 2-7.

![Figure 2-6: Prototype of circularly-polarized waveguide slot arrays with different numbers of elements designed at 60.5 GHz.](image)
2.3.2 Measured performance

The antenna aperture illumination and antenna gain in the far-field region are evaluated first. The antenna gains of the $2\times2$, $4\times4$, $8\times8$, and $16\times16$-element arrays were measured in an anechoic chamber by comparing with a standard gain horn antenna. The measured antenna gains are plotted in Figure 2-8. These gains excluding the matching losses ($1 - |S_{11}|^2$) are shown in Figure 2-8 by dashed lines. The calculated antenna gains using the simulator ANSYS HFSS are also included in Figure 2-8. The gray dashed two-dot lines shown in Figure 2-8 correspond to the antenna efficiencies of 70% and 80% associated with the different aperture sizes defined above.

Electric field distribution is calculated by measured near field distribution on the antenna aperture. The field distribution is shown in Figure 2-9. Desired electric field intensity of more than -1.3 dBV/m is obtained up to 14 m away from the antenna.
Figure 2-8: Antenna gains and directivities of the test antennas with different numbers of elements

Figure 2-9: Near field electric field distribution.
3 mmWave antennas for backhaul link

3.1 Introduction

A middle-range Fixed Wireless Access (FWA) system in the millimeter-wave band is under development in Japan to realize a maximum throughput of 2 Gbps. To utilize the frequency resources more efficiently, full duplex, also known as Directional Division Duplex (DDD) is adopted to double the transmission capacity compared to the conventional Time Division Duplex (TDD) or Frequency Division Duplex (FDD). That is, a wireless terminal in DDD will use two independent antennas operated in same frequency and with same polarization to realize simultaneous bidirectional communication. In addition, the system interference due to the obstacles existing in the directions of sidelobes should also be taken into account. For the 5G-MiEdge backhauling, high data rate is required in order to manage various kinds of application. Combination of the mmWave and DDD is one of the best choice for such application because mmWave can use wider bandwidth and DDD realize high spectrum efficiency.

In this study including the past study [IEEETAP16], a double-layer waveguide slot array is to be designed in the 40 GHz band where the transmission loss is much lower than it in the 60 GHz band. An antenna gain higher than 31 dBi and a sidelobe level lower than -30 dB are to be realized. Meanwhile, the isolation of more than 80 dB between the adjacent transmitting and receiving antennas arranged in an H-plane is also required over the operating frequency range of 39.5 to 41 GHz.

![Figure 3-1: Directional division duplex.](image)

3.2 Design and analysis results

3.2.1 Antenna configuration

The perspective view of a double layer waveguide slot array fed from four corners is shown in Figure 3-2. The outer antenna size is limited within 136.4 mm by 134.4 mm. The whole antenna is fed by a Q-band standard waveguide from the backside. The feeding circuit with four arms stretches from the center to the four antenna corners. Then, the radiation waveguides in the upper layer are fed in co-phase through slot couplers which are cut in the upper broad-walls of feeding waveguides located in the bottom layer.
3.2.2 **Design results**

The Finite Element Method (FEM) based electromagnetic field simulator, ANSYS’s HFSS is used in this work for antenna design. The full-structure analysis by HFSS is also conducted. The frequency characteristics of antenna gain and overall reflection are summarized in Figure 3-3. The antenna gain of more than 31.8 dBi and the reflection of less than -12 dB are estimated over the desired frequency range of 39.0 ~ 41.5 GHz. Figure 3-4 shows the measured isolation between those two antennas. It can be maintained up to a level of approximately 80 dB. The predicted radiation patterns in the principal E- and H-planes are shown in Fig. 4. The sidelobes are suppressed below -30 dB at 40.0 GHz.

![Figure 3-3: Predicted antenna gain, directivity and overall reflection as a function of frequency.](image_url)
Figure 3-4: Isolation characteristics.

Figure 3-5: Radiation patterns.

(a) E-plane

(b) H-plane
3.3 Experimental results

3.3.1 Fabricated antenna

Figure 3-6 shows the prototype antennas with V-polarization and horizontal arrangement [IEEETAP16]. Those two antennas for independent transmission and reception are installed on a tentative base for evaluation. The antenna is fabricated with the over-etching (30 μm) taken into account.

![Prototype antenna](image)

Figure 3-6: Prototype antenna

3.3.2 Measured performance

Measured frequency characteristics of reflection is shown in Figure 3-7. The reflection is degraded up to -9 dB. Similar tendency was observed between two fabricated antennas. Measured frequency characteristics of directivity and gain are shown in Figure 3-8. The directivity is calculated from measured aperture field distribution. The gain was measured in an anechoic chamber. The distance between Tx and Rx antennas is 6 m. Gains without the return loss are also calculated.

Radiation patterns in E and H-planes were measured as shown in Figure 3-9. Agreement with calculation was confirmed. However, degradation in shoulders were observed. The radiation patterns were measured and confirmed within frequency band.

Isolation between Tx and Rx antennas were measured using a signal generator and a spectrum analyzer. Measured isolation is shown in Figure 3-10. Isolation higher than -76 dB was confirmed.
Figure 3-7: Measured reflection characteristics.

Figure 3-8: Measured gain and directivity.
Figure 3-9: Measured radiation patterns.
Figure 3-10: Measured isolation.
4 Measurements of antennas by TIM in CATR

4.1 Introduction

The antenna measurements is an essential activity required to verify if the actual performance match the requirements. In particular, the radiation pattern has to be measured and verified because it represents the fundamental input of any design tool used in the cellular coverage prediction.

To accomplish the antenna measurement executions in a correct way (i.e., to operate in far field conditions without being influenced by perturbations of the environment) in the past the AUT were typically mounted on high towers. In a second phase, to perform measurements on antennas for cellular telephony, also outdoor antenna test range has been adopted. In the last few years, a more convenient approach based on CATR has started to be adopted because of several advantages over the older ones. This chapter introduces the CATR concept and the anechoic chamber available at TIM\(^1\) premises that will be exploited for the antenna measurements on the antenna prototypes developed within the 5G-MiEdge project.

4.1.1 Antenna measurements and related issues

The main outputs of the characterization of an antenna are the radiation patterns measured in the two main planes, namely the vertical and the horizontal, its gain and the reflection coefficient at each antenna port. In Figure 4-1 an example of radiation pattern is shown.

![Example of radiation pattern](image)

Figure 4-1: Example of vertical and horizontal measured plane

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\(^1\) TIM is the single brand that, starting from beginning 2016, identifies both the fixed and mobile network of the Telecom Italia Group (in the past the acronym TIM – Telecom Italia Mobile, identified the mobile network only).
These measurements must be performed in the \textit{Far Field} (FF) condition. Mathematically, from the theory of the antennas, the condition of FF corresponds to (if $D$ is the main dimension of the antenna):

$$d_{FF} = 2 \frac{D^2}{\lambda}$$

Let's try to derive this value for the 64x64 array designed in this project at the frequency of 60GHz.

The array has dimensions 277mm x 278mm, so the diagonal is: 392.5mm ($D$). The wavelength is 49.96mm: $d_{FF} \approx 61.66$ m

Obviously, the best condition for carrying out this kind of measurements is represented by an anechoic chamber. However, a chamber in which there are about 25 meters between the antenna and the probe can present various difficulties, like to find in the premises of a company a so large space to implement an anechoic chamber or the expensive absorber material necessary to cover this large space that must be periodically substituted to preserve its absorbing capacity.

For these reasons, in the past, a good compromise was to create an outdoor test range, but this solution has to face some critical issues:

- Atmospheric conditions (in case of rain or snow it is not advisable to perform measurements)
- Interference generated and received (in the test area it is possible to receive signals coming from other transmitters active in the area on the same frequency band).
- Permission request from the central government to use non-licensed frequencies (in the days of testing prototypes of 5G antenna system)

To overcome these difficulties and to face the critical issues, the \textbf{Compact Antenna Test Range (CATR)} is an excellent candidate.

\subsection*{4.1.2 The Compact Antenna Test Range (CATR) alternative to the FF}

Analyzing the electromagnetic field radiated by an antenna in FF condition it is possible to verify that this field can be represented, with a good approximation, as a plane wave. A parabolic surface has the property of transforming a plane wave front (far field) into a spherical one, concentrating it in a point called focus. In this way, in a CATR is present a parabolic reflector where the field radiated by a probe is reflected and transformed in a plane wave or, as if it were in electromagnetic far field\footnote{If the AUT is transmitting and the probe receiving, the property before reported is always valid for the reciprocity of the whole system} condition. Obviously, this is an approximation due several reasons:

- the surface roughness and the precision of the parabolic shape of the reflector;
- the dimensions of the reflector with respect to the wavelength in the whole band of the CATR;
• the presence of the absorber material which minimizes but not eliminates the reflections.
• all the infrastructures in the anechoic chamber required for the practical use of the system (RF cables, handles to open and close the room, walkable areas to access the devices/apparatus located in the room, any metal frame supporting the elements of the room that, although shielded with absorbent material, can still impact the measurement results).

In any case, the company in charge of the CATR operations, by means of measurements, certifies that the above mentioned approximations are sufficiently negligible and the measurements carried out are comparable with others carried out in a real far field test range.

4.2 Elements of a CATR

4.2.1 The reflector

Is the earth of the CATR. Many of the characteristics of the measuring system depend on its quality. It is made by numerical control machines, in one piece, in order to avoid joints and welds that would alter the parabolic surface. The time required for its construction is generally high in order to allow the CNC (Computer Numerical Control) machine to keep the parabolic shape and the surface roughness always under a certain tolerance.

Figure 4-2: Example of two reflectors realized by NSI-MI [NSI1], [NSI2]

Figure 4-2 reports two reflectors realized by NSI-MI characterized by serrated edges: these are designed so as to minimize diffraction and in any case all those signals that a sharp edge could generate by altering the plane waveform used for measurements.

4.2.2 The probe

It is usually a rectangular or circular horn. The probe can rotate so as to follow any roll rotations (see figure 4-3). This element is put in the focus of the parabolic reflector. The CATR generally has several probes, supplied with the system, and able to cover the entire operating band of the measurement. The optimal condition is that between a probe and the next one, there is a region of the spectrum where the two elements overlap.
4.2.3 The Quite Zone

It is nominally the volume in which it is guaranteed that the field is adequately represented by a plane wave. The DUT (Device Under Test) is placed in this region, by means of a mast. The size and shape of the Quite Zone are generally depending on the dimensions and characteristics of the anechoic chamber itself.

4.2.4 The mast

The mast is where the AUT is installed. This type of mast provides different degrees of freedom allowing the motion of the AUT into azimuth, roll, and elevation. Sometimes the mast is also mounted on a sliding sled to allow the motion of the AUT back and forth in order to place it in the center of the Quite Zone (see Figure 4-3).

![Figure 4-3: Degrees of freedom of the mast](image)

This system provides all these degrees of freedom also to implement measurements such as conical cut. In fact, when an antenna can irradiate the signal with a down tilt different from zero, the measurement of the horizontal plane must be carried out in the plane in which the antenna has the maximum gain, namely through the so-called conical cut. In a test range where the height of the probe can be modified, it is simple to vary the height of the probe in order to achieve the desired cut. In the CATR where the position of the probe is fixed (at the focus of the reflector), to perform the same measurement it is necessary to combine movements of roll, azimuth and the probe. The maximum weight of the antennas that can be measured is limited by the power of the motors of the mast.

4.2.5 The absorber material

Last but not least is the absorber material. It is a spongy material impregnated with graphite. The typical shape is pyramidal. The height of these pyramids is related to the wavelength even if sometimes it depends exclusively from geometrical reasons (joining region of two walls).
4.2.6 The quality of a CATR: main parameters

- Frequency Band
- Quite Zone Shape
- Quite Zone Dimension
- Maximum Cross Polarization
- Amplitude total variation @Quite Zone (QZ)
- Amplitude taper @QZ
- Amplitude ripple @QZ
- Phase ripple @QZ
- Reflector Dimension
- Focal distance
- Surface accuracy (QZ area)
- Surface accuracy (QZ outsize)

4.3 The CATR in TIM

The measurement system present in TIM can be configured as CATR or Spherical far-field-near field. The latter will be briefly described in sections 4.3.3 and 4.3.4. In the following section 4.3.1 are reported sketched images and photos of the CATR installed in TIM as well as its main characteristics (sec. 4.3.2)

4.3.1 Descriptions

![Figure 4-4: Absorbing material layout design](image)

In the Figure 4-4 is reported an ensemble view of the chamber. In the Figure 4-5 is reproduced a wall with absorber material where is visible the difference of dimensions of the pyramids near and far the edges.
Figure 4-5: Absorbing material design: rear reflector wall

In Figure 4-6 is reported the CATR + Spherical NF-FF system.

Figure 4-6: Complete mechanical system overview

In Figure 4-7 a top view of the complete camber is reported.
In Figure 4-8 the CATR putting in evidence main distances.
Figure 4-8: CATR System

Figure 4-9: The base of the mast

Figure 4-9….Figure 4-14 are photographs of some details of the room
Figure 4-10: Frontal view of the mast

Figure 4-11: Side view of mast
Figure 4-12: The reflector with the serrated edges

Figure 4-13: The probe
4.3.2 Main characteristics CATR

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<tr>
<th>Parameter</th>
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<td>dB</td>
<td>0.5 (20 – 40 GHz)</td>
</tr>
<tr>
<td>Amplitude ripple</td>
<td>dB</td>
<td>± 0.75 (&lt; 15 GHz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 0.4 (15 - 50 GHz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 0.5 (50 – 110 GHz)</td>
</tr>
<tr>
<td>Phase ripple</td>
<td>degrees</td>
<td>± 8° (&lt; 15 GHz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 4° (15 - 50 GHz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 5° (50 – 110 GHz)</td>
</tr>
<tr>
<td>Reflector dimensions</td>
<td>cm</td>
<td>218x218</td>
</tr>
<tr>
<td>Focal distance</td>
<td>cm</td>
<td>350</td>
</tr>
</tbody>
</table>
### 4.3.3 The Near Field configuration and concepts of measurements

Consider the electromagnetic field radiated from a source. The source can be incorporated into a convenient surface (e.g. sphere) where the field is measured in amplitude and phase (Near Field). For the equivalence principle, starting from the electromagnetic near field values on the surface, by means of a mathematical transformation (NF-FF) it is possible to obtain the radiation patterns desired.

In the anechoic TIM chamber, in this configuration, the reflector must be shielded (Figure 4-15).

![Figure 4-15: The Spherical NF-FF configuration](image)

### 4.3.4 Main characteristics of Spherical NF-FF

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band</td>
<td>GHz</td>
<td>0.69 – 18</td>
</tr>
<tr>
<td>AUT maximum size diameter</td>
<td>m</td>
<td>2</td>
</tr>
<tr>
<td>Directivity and Gain measurement</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Typical cross polar level</td>
<td>dB</td>
<td>-50/-60</td>
</tr>
<tr>
<td>Full pattern measurement</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Pattern precision</td>
<td></td>
<td>Limited by absorber reflectivity</td>
</tr>
<tr>
<td>Standard Gain Horn calibration</td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>
4.4 Measurements of active antennas

These are a new generation of antennas where the main characteristics is that the radio frequency modules are integrated in the antenna. This means that the input of the antenna is not a RF cable but one or more optical fiber. Having a digital input, many of these antennas enable beam forming or beam switching techniques.

Traditional measurement techniques (by means of a vector network analyzer) in this kind of antennas cannot be applied because RF ports are not available. A possible solution to overcome this issue relies in the exploitation of the reference signals necessary for the operation of any cellular system.

In order to allow the channel estimation in the receivers or to support the required physical layer procedures, in any cellular system are radiated some standardized reference signals (e.g., pilot channels, ...) known to both the transmitting and receiving side. At the receiver, observing the impairments experienced by these known signals it is straightforward to identify the multipath introduced by the propagation channel.

But in LOS, the signals are substantially unaffected by these undesired degradations, (they suffer just the attenuation due to the free space propagation). Assuming to be able to extract the reference signals from the received physical layer frames, it is possible to derive the antenna pattern. In fact, since the reference signals are transmitted at constant power, the only power variations that can be detected at the receiver are exclusively due to the radiation pattern of the AUT itself.

The implementation of these concepts could be achieved by means of a signal analyzer able to extract the necessary information from the received physical layer frames.

The choice of TIM instead, taking advantage of the knowledge acquired in recent years about SDR boards and in the processing of the physical layer of the LTE system has been different.

An alternative approach, widely used at TIM CATR in the last few years is based on SDR boards able to process the physical layer of the received signal.

A USRP board can be used as a sampler of the signal received from the probe and this signal can then be adequately processed using a software customized for the purpose. For example, this solution has been systematically adopted with the LTE signals according to the steps described in section 4.4.1.

4.4.1 Phases of an analysis of an active antenna

- Antenna mounted on the mast, and radiating a signal compliant with a cellular idle state or a convenient test model.
- Antenna rotates in the azimuth plane while the probe receives the transmitted signal.
- The USRP board acquires the base band LTE signal.
- The custom software extracts the reference signals.
• By means of a relationship between the azimuth position of the mast and the signal received, obtains the radiation pattern.

The advantages of this implementation is the speed of execution of the measurements (otherwise for each measuring point it is necessary to wait for the processing time of the instrument).

If the antenna is able to transmit simultaneously two or more cells (by means of more than one beam), characterized by different cell id, with this approach it is possible to measure the different cells using only one acquisition.

The main disadvantage of this method is represented by the large amounts of data to be stored.

4.5 Examples of Measurements

4.5.1 Passive antenna CATR

Figure 4-16: Radiation patterns
4.5.2 Active antenna

Figure 4-17: Radiation patterns
5 Summary

A 5G enabled stadium like the one considered for the 2020 Tokyo Olympic use case represents one of the most challenging use cases of extreme mobile broadband due to both the very high bit rate requirements per single connection and the very high user density. In addition, the expected provision of advanced multimedia services like, for example, immersive communications, introduce strict delay requirements making even more difficult the design of an adequate communication system. In this context, it becomes nearly unavoidable to operate in the mmWave frequency range. One of the key component of the communication system able to satisfy the demanding requirements of the use case are the specific mmWave antennas designed ad hoc within the project. This deliverable reports design and measurement results for two of the mmWave antennas designed for a 5G enabled stadium: the antenna to be used to realize the “information shower” installed at the gates of the stadium and the antenna to be used for the backhaul link. The antenna destined to the information shower is a passive 32x32 element array antenna operating in the 60 GHz frequency band. Such a kind of antenna is able to provide an adequate radio coverage in a limited area close to the entrance/exit ports of the stadium allowing then the fast download at extremely high bit rate of files related to the events occurring at the stadium.

The antenna to be used in the backhaul link is a 20x20 element array antenna designed for operation in the 40 GHz frequency band. In order to utilize the frequency resources more efficiently, a Directional Division Duplex is adopted to double the transmission capacity compared to the conventional TDD or FDD.

Furthermore, the CATR system that will be used for experimental evaluation of the mmWave antennas is presented. Such a kind of solution eases the measurement activities reducing the needs for the availability of large areas.
6 References

[D1.1] 5G-MiEdge public deliverable D1.1. Available online at 5g-miedge.eu


[KDDI] https://www.youtube.com/watch?v=muogdOHCJu0

