# ECC Report 342

Microwave PMP technologies based on active antennas for 5G backhaul above 27.5 GHz

**approved 7 October 2022**

# 0 EXECUTIVE SUMMARY

This Report describes a Point-to-Multipoint (PMP) system intended to operate within Fixed Service (FS) for backhaul applications which implements a star topology by leveraging on an active antenna (AAS) configured to synthetise multiple beams, connecting the central station to several stations. The Report is a technical description of the PMP system which includes the key technologies (beamforming and interference cancellation techniques) and some possible deployment cases (low density site and high density site).

This Report contains simulations and measurements made using available prototype in an attempt to show the feasibility of the concept, including compliance with relevant standards and requirements for the fixed service. In particular, compliance with the relevant ETSI emission masks both in azimuth and elevation is assessed for co-polar signal (see section 3.4.2), including a sensitivity analysis relative to operating frequency and antenna element spacing. Applicability of ERC Recommendation 74-01 [10] for compliance with unwanted emission limits of the system is assessed as well (see section 3.4.3). At the time of developing this Report, no ETSI standard for Fixed Service equipment properly takes into account the specificity of the active antennas considered, where no antenna connector is available.

This Report does not contain sharing or compatibility studies both within the FS and with other services that may be used as the basis for regulatory measures and equipment harmonisation in a specific band. Furthermore, it does not contain any information on the actual Out of Band (OoB) emissions from the PMP system using AAS and as such it does not include verification or assessment of quantity or quality of unwanted emissions.

This Report is not band-specific, and it considers a PMP system using AAS in FS bands above 27.5 GHz; therefore, the concept could be applied to any other mmW frequencies. It is to be noted that the current PMP ETSI standard considers only frequency bands up to 43.5 GHz.

It is important to highlight that, even if the proposed new PMP system uses some technologies widely used by mobile networks, the system can only fall, in all aspects, within FS category since no mobility is present or foreseen neither at the central station nor at the connected fixed stations. This applies to the antenna pattern as well which is in general static within a certain tolerance due to e.g. temperature and not changing in time, once the PMP system has been configured (or re-configured).

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# LIST OF ABBREVIATIONS

| Abbreviation | Explanation |
|---|---|
| **AAS** | Active Antenna Systems |
| **ACM** | Adaptive Coding and Modulation |
| **CEPT** | European Conference of Postal and Telecommunications Administrations |
| **CIR** | Committed Information Rate |
| **ECC** | Electronic Communications Committee |
| **e.i.r.p.** | Equivalent Isotropic Radiated Power |
| **FS** | Fixed Service |
| **FSS** | Fixed Satellite Service |
| **mmW** | Millimeter Wave |
| **MW** | MicroWave |
| **PIR** | Peak Information Rate |
| **PoP** | Point of Presence (of optical fiber) |
| **PMP** | Point-to-Multipoint |
| **P-P** | Point-to-Point |
| **RPE** | Radiation Pattern Envelope |
| **SINR** | Signal to Interference and Noise Ratio |
| **TRP** | Total Radiated Power |
| **XPIC** | Cross Polar Interference Cancellation |
| **TDD** | Time Division Duplex |
| **FDD** | Frequency Division Duplex |
| **T/R module** | Transmit/Receive module |
| **SDM** | Space Division Multiplexing |
| **SDMA** | Space Division Multiple Access |
| **ADC/DAC** | Analog-to-digital converter/digital-to-analog converter |
| **S/N** | Signal to Noise Ratio |

# 1 INTRODUCTION

The introduction of 5G systems and networks is raising new requirements to their transport capacity, especially their backhaul. This Report describes a Point-to-MultiPoint (PMP) system intended to operate within Fixed Service (FS) for backhaul applications which implements a star topology by leveraging on an active antenna (AAS) configured to synthetise multiple beams, connecting the central station to several stations. The Report is a technical description of the PMP system, which includes the key technologies (beamforming and interference cancellation techniques) and some possible deployment cases (low-density site and high-density site). In this regard it is important to highlight that, even if the addressed PMP system uses some technologies widely used by mobile networks, the system can only fall, in all aspects, within the FS category since no mobility is present or foreseen, neither at the central station nor at the connected fixed stations.

## 1.1 CAPACITY REQUIREMENT

The available capacity for wireless backhaul is strictly related, among other factors, to the amount of available spectrum and channel width that can be used. The interdependence among frequency, capacity and availability is illustrated in Figure 1.

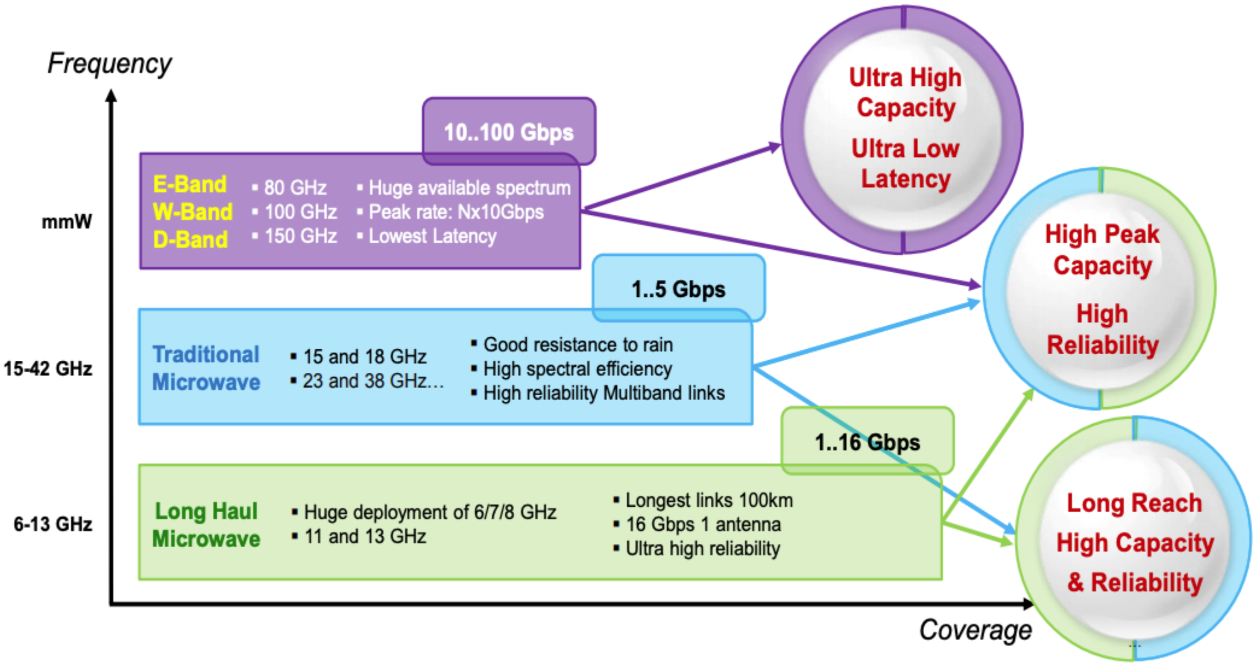

Figure 1: Interdependence among frequency, capacity and availability

Traditional mmW bands over 27.5 GHz have a maximum channel width of 224 MHz, whilst E band, W band and D band have a channel width of 250 MHz and multiples. Traditional microwave bands are limited with available amount of spectrum (about 2 GHz per band) which limits the capacity. With a larger amount of spectrum available, such as in the E band (71-76 GHz/81-86 GHz - 10 GHz), W band (92-114.25 GHz – 18 GHz), and D band (130-174.5 GHz - 30 GHz) with channel widths of 250 MHz and a possibility of flexible channel aggregation, channel capacities higher than 5 Gbps can be achieved.

The peak values in Figure 1 can be achieved as long as sufficient spectrum is available in terms of either channel aggregation or channel width.

## 1.2 TOPOLOGY REQUIREMENT

When area traffic capacity and connection density are increasing in a large scale, a higher site densification will follow. Moreover, the fibre is penetrating to the edge of the network. The above two aspects have two main effects:

- Shortening of chains of cascaded radio links as the number of hops from microwave site to fibre is getting lower, approaching the limit of one radio link to the fibre;
- Increase of the number of links originating from a hub site to the leaf sites[1].

In general, these considerations lead to the definition of different network segments:

- Dense Urban and Urban scenarios: where previously the network was based on a hub-and-spoke kind of topology, there is a strong increase in fibre Points of Presence (PoP), from which a star topology of high capacity tail links originate; the fan-out of such hubs tends to be high. The depth of the MW/mmW network tends to become 1 to 1.5 hops from the fibre PoP;
- Sub-urban scenarios: the trend is the same, but here the MW/mmW network depth is going towards an average of 1.5 to 2 hops from the fibre PoP;
- Rural scenarios: here the variance will be greater due to the widely different geographical conditions, but it is expected that the average network depth should tend towards 2.5 hops from the fibre PoP;
- Mixed scenarios: in some places, it may happen that a small cluster of urban or suburban sites are situated at a certain distance from the fibre PoP, so that the MW/mmW link length for the aggregation link towards the PoP is not directly related to the cell radius.

As a result, the network topology, especially in dense area, is evolving from linear to star, with high-capacity, and shorter distance as shown in Figure 2. This kind of backhaul is expected to be characterised by variable behaviour, somehow closer to the access behaviour than to traditional backhaul. Traffic asymmetry, time variability, weather and style of living–dependent characteristics can be examples of possible sources of variability. Such new backhaul requirements could be possibly addressed by using links/network configurations other than Point-to-Point.

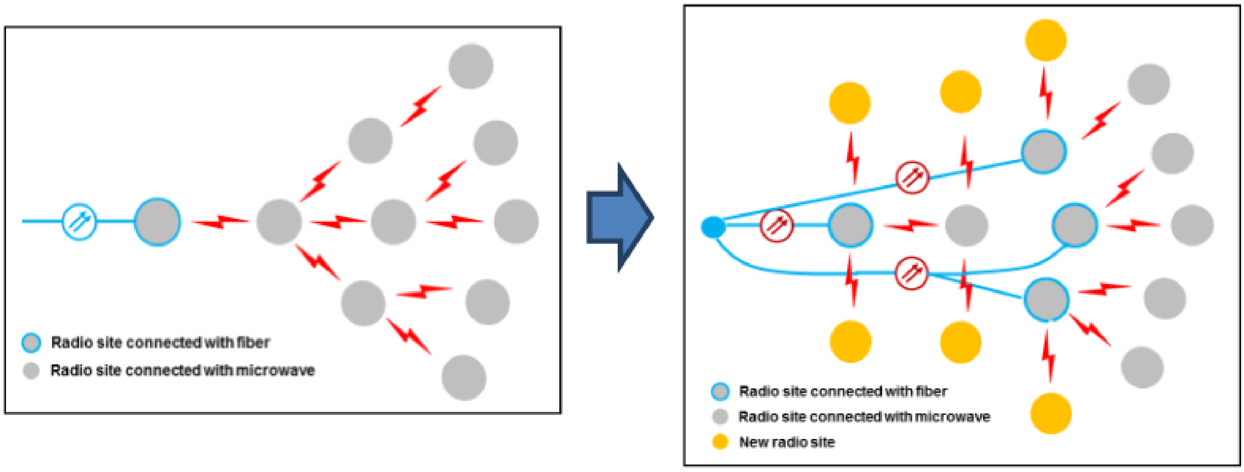

Figure 2: Topology evolution in backhaul network

## 1.3 MITIGATION OF HEAVY BURDEN OF ANTENNA ON INSTALLATION SITES

A traditional microwave parabolic antenna usually has a diameter of 30 cm or 60 cm according to the required gain.

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[1] Hub site is the center of the star topology and understood as Central Station. Leaf sites are the peripheral sites in a star topology and understood as Terminal Station,

The AAS prototype considered in this Report would occupy an area of about 30 cm x 60 cm, covering an entire 120 degrees sector.

So in the case of a hub site with 8 links per sector an AAS would occupy about 1/4th of the area of eight 30 cm FS antennas or about 1/16th of the area of eight 60 cm FS antennas.

## 2 KEY TECHNOLOGIES FOR NEW PMP SYSTEMS

In this section, the fundamental technologies that are at the base of a new PMP system are presented:

- Active phased array antenna;
- Beamforming;
- Beam-nulling;
- Interference cancellation.

### 2.1 ACTIVE PHASED ARRAY ANTENNA

The active phased array antenna is an array of antenna elements with integrated active components designed to change the antenna radiation pattern in terms of shape and direction of the beam. In an active phased array antenna, the RF signal from the transmitter is fed to the individual antenna with the correct phase relationship so that the radio waves from separate antennas adding together increase the radiation in a desired direction, while cancelling to suppress radiation in undesired directions. In a phased array, the power from the transmitter is fed to the antennas through beamforming technology described in section 2.2.

An active phased array antenna contains antenna array and digital signal processing (DSP) running algorithms, which make it possible for the antenna to transmit and receive signals to perform adaptation in a desired way, shown in Figure 3. A typical block diagram of a T/R module for an antenna element in an active phased array antenna in shown in Figure 4.

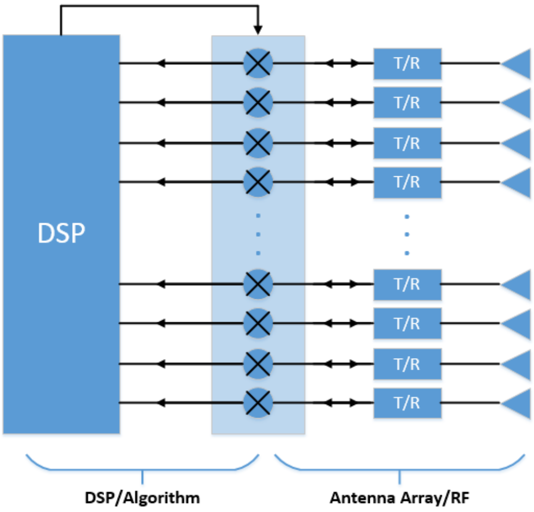


Figure 3: Block diagram of an active phased array antenna

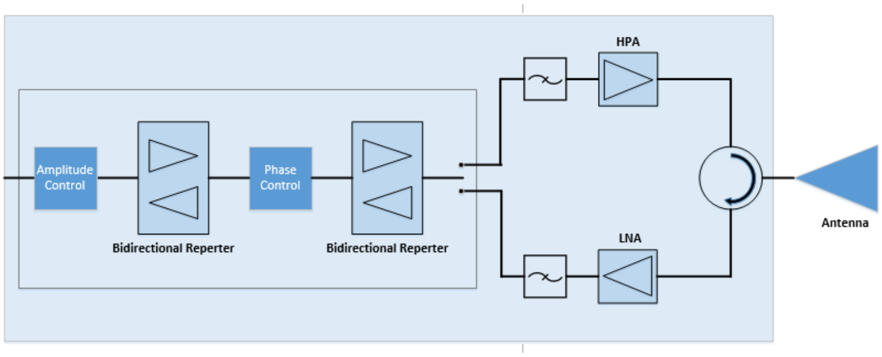


Figure 4: Block diagram of a T/R module for an antenna element in an active phased array antenna

As active antenna contains active components which are much smaller than passive components, active phased array antenna can integrate multiple array antennas inside as shown in Figure 5, with comparable size to the traditional parabolic antenna, making multi-antenna array implementation possible and thereby reducing the number of antennas at hub site.

**Parabolic Antenna** **Active phase array Antenna** **Implementation of antenna array**

Figure 5: Parabolic antenna and integrated phased array antenna

### 2.1.1 Technology limitations

Active phased array antenna systems are subject to some impairments and limitations that can be reduced but not eliminated with a proper design. The main ones are:

- limited amplitude control range;
- limited phase control accuracy;
- mutual coupling among elements;
- internal losses (ohmic, impedance mismatch…);
- local oscillator phase noise;
- random errors;
- intermodulation.

The evaluation or prediction of the performance of array antennas in the presence of elemental excitation variations (due to environmental and operational factors including failures) is an important part of the engineering effort in the development of high-performance antennas. An active antenna radiation pattern will differ from the theoretical pattern because of dispersion of the characteristics between active chains which create a distortion of the amplitude and phase illumination laws. Different types of errors can be described. Errors can be divided into two types depending on whether they are predictable or random:

- Predictable errors (such as reproducibility, assembly and thermal gradient defaults) can be compensated by antenna calibration at calibration points (frequency and/or temperature) at equipment level;
- Random errors are caused by the accidental deviations of the antenna parameters from their design value. These deviations will occur at the beginning of life (due to characteristic dispersions of each and between equipment) and will change throughout the antenna life to finally give the end of life antenna performance. Although they may be small, they will affect the antenna main beam and side-lobe gain performance.

## 2.2 BEAMFORMING

Beamforming is a signal processing technology used to change the direction and the shape of radiation pattern of the array antenna for either signal transmission or signal reception. It is achieved by combining elements in the array in a way where signals at particular angles experience constructive interference and while others experience destructive interference.

Beamforming technology is used in the PMP structure to automatically make alignment with hub site and leaf site. Figure 6 shows the internal diagram of beamforming. Multiple RF channel signals are transmitted at the same time and are combined in the air. The amplifier and phase shifter of each RF channel could be adjusted, in order to change the shape and phase of the beam, and then change the pointing direction of the beam combination.

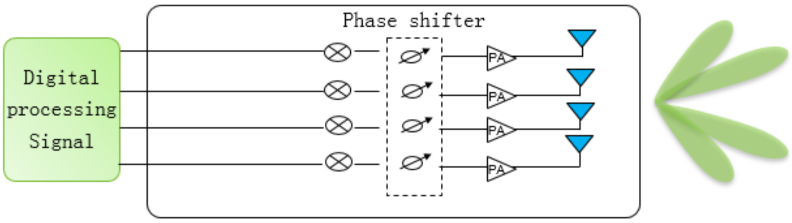


Figure 6: Internal diagram of beamforming

Along with the technology development, there are several kinds of beamforming implementation, depending on where the limit between the analogue and the digital parts is placed.

Intermodulation can occur when beams are formed at different frequencies in a relatively wide bandwidth as 3rd order products may fall in-band and are efficiently radiated. A large output power amplifier back-off may be required to limit radiated intermodulation ratio to acceptable levels. Antenna systems where such radiation intermodulation can occur require further study. However, the PMP system described in this Report uses just one carrier frequency per sector so that intermodulation would not occur.

### 2.2.1 Analogue beamforming

Analogue beamforming typically consists of only one RF chain and only one couple of ADC/DAC (converters) and multiple analogue amplitude and phase shifters that feed an antenna array, as shown in Figure 7. It holds the advantages of low cost, simple structure and easy implementation, but could only produce one single beam combination at a time, and also is limited in power and performance as analogue phase shifter is used.

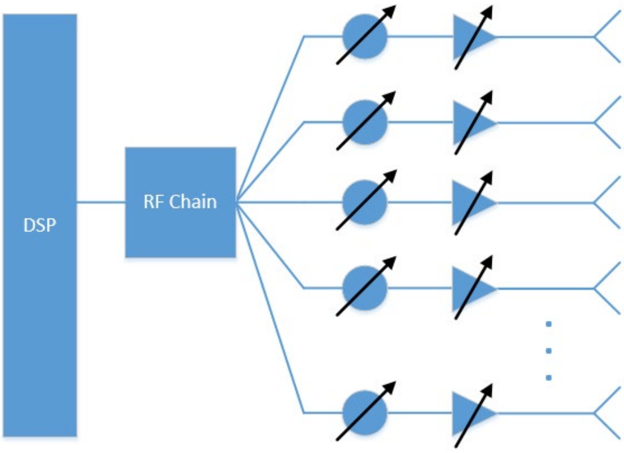


Figure 7: Analogue beamforming

### 2.2.2 Digital beamforming

Digital beamforming consists of multiple RF chains and multiple digital amplitude and phase shifters that feed an antenna array. In this architecture, each RF chain is connected to digital converters (i.e. ADC and DAC), as shown in Figure 8. It holds more sophisticated structure than analogue beamforming and then has higher cost and higher power consumption. However, digital beamforming can produce multiple beam combinations simultaneously, as each antenna element fed by a digital amplitude and phase shifter is connected to a RF chain. And also due to this structure, one signal could be distributed to all antenna elements through digital amplitude and phase shifter, and then could take advantage of the total gain from all the antenna elements, with the result to achieve high transmitting power. As digital shifter has higher accuracy than analogue shifter and DPD (digital pre-distortion) could be used, the RF performance would be increased.

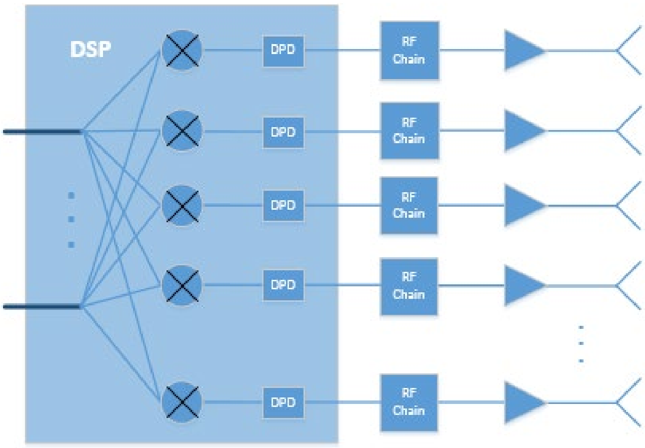


Figure 8: Digital beamforming

### 2.2.3 Hybrid beamforming

In order to acquire balance between cost, power consumption and performance, hybrid beamforming is introduced, in which several antenna elements fed by an analogue amplitude and phase shifter are connected to a single RF chain to form a sub-array and then several sub-arrays are connected to digital amplitude and phase shifters form an antenna array, as shown in Figure 9.

This architecture keeps the advantages of both analogue and digital, allowing to control several beams at lower power consumption and cost.

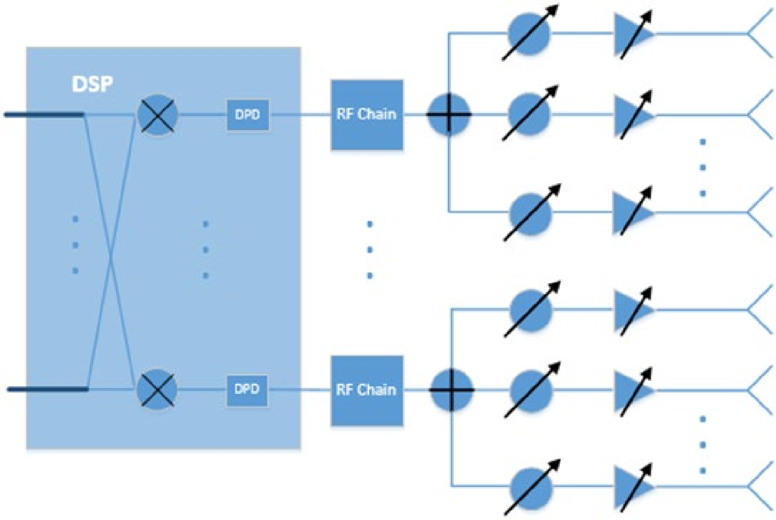


Figure 9: Hybrid beamforming

## 2.3 BEAM-NULLING

Beam-nulling technology is a way to reduce interference by introducing nulls in the antenna pattern. In general it can be used both in TX, to minimise the emission in the direction of victims, and in RX, to minimise the reception in the direction of the interferer. In a general sense, beam-nulling can be considered as part of beamforming technology, taking into account that the possibility to define the shape of an antenna pattern in both peaks and nulls is limited by the degrees of freedom of the system depending on the number of antenna elements and on the number of amplitude and phase controls.

In a PMP system, it can be used to counteract the possible interference among the different directions: once that the main beam is directed towards the wanted leaf, the side-lobes of this signal could be in general interfering the other leaves unless nulls are imposed in the directions of the other leaves.

Beamforming and beam-nulling are obtained by specific algorithms, so that the SINR of current antenna array is maximised in the desired direction, under the condition that the main lobe power of the current signal is kept unchanged and that the side lobes are suppressed in the unwanted directions.

An example is shown below. The network topology, depicted in Figure 10 on the left, is made of 1 hub site and 5 leaf sites. Considering link L1, the signal from the hub would have in general side-lobes in the direction of the other leaves. In order to minimise the interference from L1 impacting L2 to L5, specific algorithms are implemented in L1, aiming to maximise the SINR. The same mechanism is applied for the other links. The antenna radiation pattern towards L1 with beam-nulling applied is shown in Figure 10 on the right.

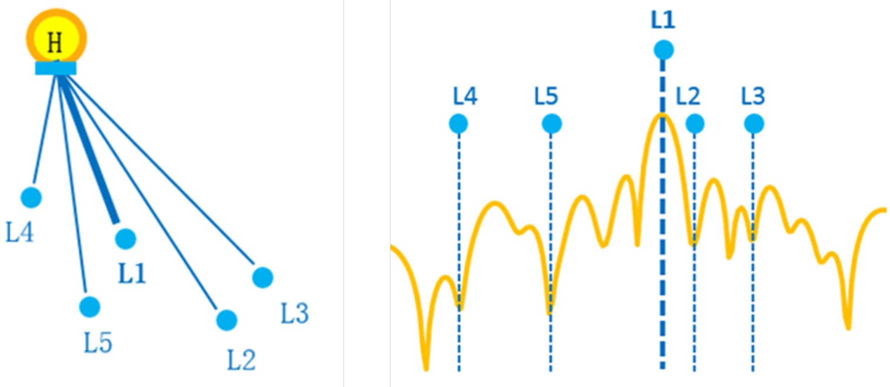


Figure 10: Example of beam-nulling

The following limitations should be noted:

- main beam gain loss from the application of nulling function;
- main beam gain loss when interferers are close to the intended direction.

## 2.4 INTERFERENCE CANCELLATION

As multi-beam is used, each beam can cause mutual interference to the other beams and then SINR and capacity may decrease in victim leaves. This intra-system interference is highly dependent on the angle between adjacent links, the smaller the angle the higher the possible interference, considering the assumption to use the same frequency all over the 3 sectors of the same hub. It is important to note that this issue is also true for independent adjacent P-P link converging on the same central hub, unless using different frequencies (but in this case the spectrum efficiency would be reduced). To solve this problem, interference cancellation technology is introduced.

According to different transmission directions, there are two types of interference cancellation technologies.

The first type is from leaf sites to hub site. As all the signals from each leaf site are received by hub site, interference cancellation is implemented in the receiving direction at hub site, by exchanging signals received from each leaf site to eliminate the accompanying interference, with utilization of channel matrix obtained through a channel estimation algorithm.

The second type is from hub site to leaf sites. As the leaf sites are far away from each other, it is impossible to send signal from one leaf site to another leaf site. Then interference cancellation is implemented in the transmitting direction at each leaf site, by pre-coding the interference cancellation signal into the transmitting signal, with utilization of channel matrix obtained through a channel estimation algorithm.

In both cases, the channel estimation algorithm is done at the hub, where resides the knowledge of the different channels to/from the leaves.

# 3 DESCRIPTION OF A NEWPMP SYSTEM

The traditional implementation of a PMP system is based on star topology with a hub employing a sector antenna (it could be 90°, 120° or other) and several terminals using a directional antenna. With such a structure the multiplexing from the hub to the terminals and the multiple access from the terminals to the hub can be done either in time domain or in frequency domain or in combination. One of the limits of such system is that the gain of a traditional sector antenna is quite limited, impacting the link budget. Another limit is the narrow bandwidth of these traditional systems.

The new architecture for PMP is based on the technologies described in the previous section. The PMP structure is shown in Figure 11. Hub site uses sectored multi-beam antennas to connect leaf sites. Each sectored multi-beam antenna covers $\alpha^{\circ}$(sector) and holds n flows connected to leaf sites.

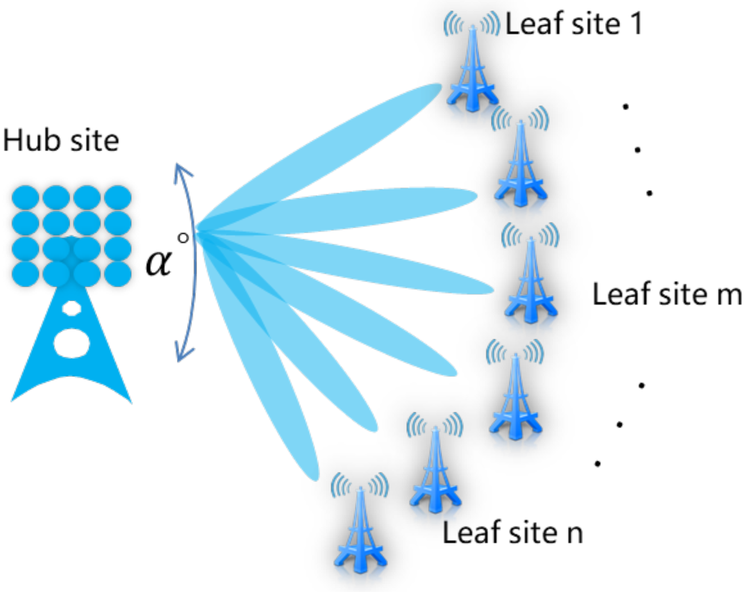


Figure 11: General structure of new PtMP system

## 3.1 SYSTEM OVERVIEW

### 3.1.1 Network topology

The PMP structure is a typical Point-to-Multipoint network topology, which provides a communication route (on a single radio channel in each sector) from hub site to a number of leaf sites. In general, each leaf site communicates with hub site by a single pathway.

### 3.1.2 Multiplexing method

Multiplexing method is used to multiplex together the signals from a central station to a number of terminal stations to allow the radio medium to be shared effectively among the various traffic paths, typically under control of the central station.

The hub site of PMP structure is able to transmit signals simultaneously in all links to leaf sites on the same frequency, so using SDM – Space Division Multiplexing, in which physical separation of transmitting paths allow to deliver simultaneously different data streams from central station to multiple terminal stations.

### 3.1.3 Multiple access method

Multiple access method is used to provide multiple access from a number of terminal stations to one central station, thus sharing the available radio capacity into the central station among the traffic requirements of the terminal stations.

The leaf sites of PMP structure are able to send signals simultaneously to the hub site on the same frequency, so using SDMA – Space Division Multiple Access, in which physical separation of transmitting paths allow to deliver simultaneously different data streams from multiple terminal stations to central station.

### 3.1.4 Duplex method

Duplex method is used to separate the two directions of signal in a bi-directional link. In the PMP structure, both TDD - Time Division Duplex and FDD - Frequency Division Duplex can be used as duplex method.

### 3.1.5 Antenna pattern

The antenna pattern in this kind of system is dependent on the specific deployment scenario, where the geographical positions of the leaves are known as well as the positions of possible stations of other systems.

Based on the known geographical data the antenna pattern, as a result of beamforming and beam-nulling, is defined in the radio planning phase and it is not changing anymore after configuration (or re-configuration in case of addition of new leaves).

Consequently once the system has been configured (or re-configured) its antenna pattern is static and not changing in time, apart from the limited drift effects due to temperature and aging applicable to every equipment. A proper automatic calibration procedure to be repeated with a due periodicity is able to counteract effectively these slow effects.

In order to understand the principle a simple example with just three leaves is showed here. It has been assumed to have three leaves on the same elevation plane and with different azimuth angles in a sector, according to Figure 12.

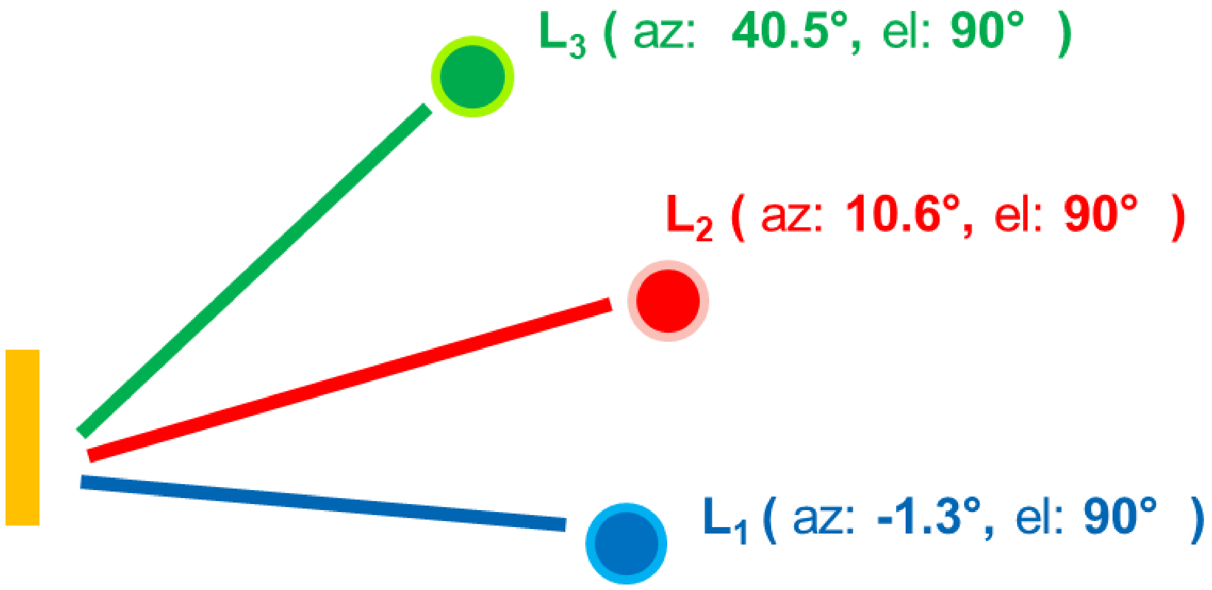


Figure 12: Simple topology example

The resulting total antenna pattern is a superposition of the single ones from the node towards each leaf, with beam-nulling applied per each leaf in the direction of the other two, as shown in Figure 13, Figure 14 and Figure 15.

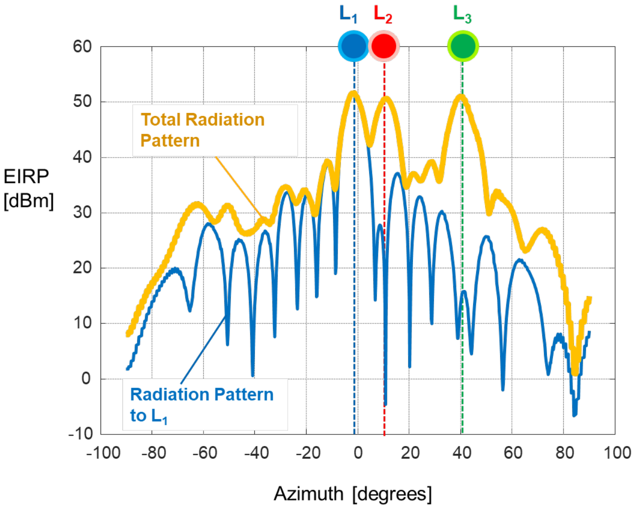


Figure 13: Radiation pattern to leaf 1

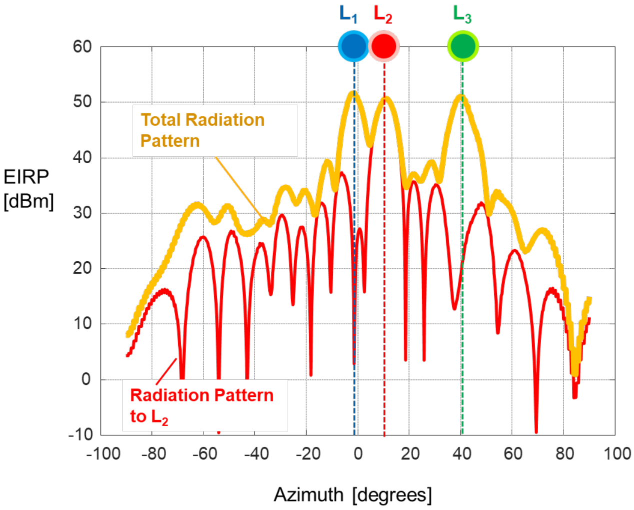


Figure 14: Radiation pattern to leaf 2

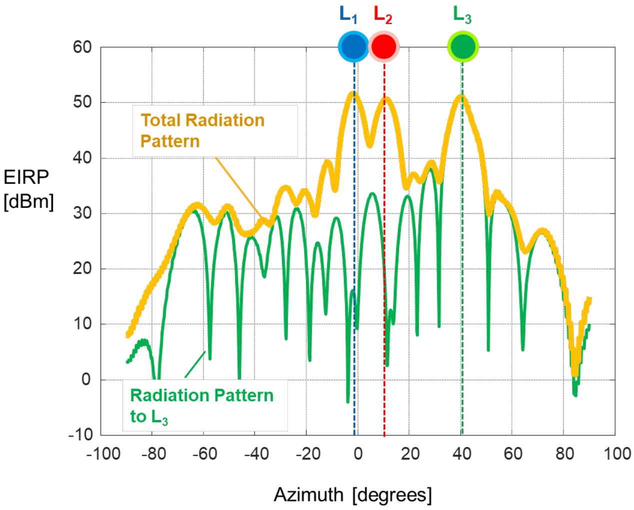


Figure 15: Radiation pattern to leaf 3

The radiation pattern towards each single leaf is just theoretical since it assumes no radiation pattern towards the other leaves, whilst the total radiated pattern obtained from the superposition of the three individual patterns represents the real emission from the node, showing peaks in the wanted directions with significantly lower side-lobes elsewhere.

## 3.2 BAND CONSIDERATIONS

This Report describes PMP technology in frequency bands allocated to FS above 27.5 GHz.

In order to consider possible bands for the PMP system it is important to highlight that the system is fixed. Even if it employs some technologies used also by specific mobile systems (e.g. IMT-2020), nevertheless the new PMP is not mobile because both the node and the terminals are in fixed positions (no mobility); its target application is mobile backhaul and no direct user access is considered. Moreover another important difference is that its antenna pattern is fixed while in use and not continuously adaptive as used in mobile networks.

This PMP system can be operated within Fixed Service provided that it can comply with existing regulatory and technical conditions defined for FS.

The PMP system can be developed in different frequency ranges assigned to FS, taking into account different factors:

- Possibility to achieve the availability target with the wanted link lengths;
- Availability of sufficiently large band and channels (to fulfil emerging backhaul capacity requirements);
- Not already crowded frequency range;
- Reasonable extension of array antenna (dependent on wavelength);
- Availability of components;
- Current regulatory framework and channel arrangements for the FS in the considered band.

Taking into account all these various factors the most favourable bands for such system have been considered in the mmW range.

Several mmW bands assigned to FS could be fit to this system. The availability of technology and components is a critical factor for the choice of the band, as well as a sufficient spectrum to achieve the targets on capacity.

When analysing the FS channel arrangements for a possibility of accommodating a new PMP system with AAS, it is important to consider not only channel bandwidth and its aggregation feasibility but also technical characteristic of FS systems and other assumptions which were made during development of those FS channel arrangements. It is necessary to ascertain whether the characteristics of the new PMP system are within the characteristics of existing fixed systems using the band. The new PMP system shall allow continuous use of spectrum by incumbent fixed systems and other services without any constraints.

## 3.3 EXAMPLE SYSTEM SIMULATION

In this section two use cases based on real deployment situations are considered as an example demonstration of the PMP system:

- a medium density site with 11 links;
- a high density case with 21 links.

Simulations are performed in a specific mmW band in order to properly show system behaviour by comparing simulation results and measurements on a prototype PMP system. However this is not an indication of any preference or suitability on this band.

The analysed system behaviour is applicable also in case of implementation in different bands, provided that the capacity is dependent on the available bandwidth, in terms of channel width and channel aggregation.

Consequently the band specific part is described into Annex 2 whilst the general part, which is applicable to any frequency band by considering the proper scaling factors (for example in terms of propagation loss and antenna dimensions) is described in the main body.

Two configurations are considered as significant examples of medium and high density site, respectively 11 and 21 links converging to a hub over the full azimuthal range. The parameters of hub and leaves heights and distances are taken from a real deployment case.

The channel model used for the simulations is pure Line of Sight (LOS) as expected for backhaul application. Thus, usual Free Space Loss (FSL) attenuation is computed. The model for phased array antenna system is taken from Recommendation ITU-R M.2101-0 [7] that is the in-force reference for AAS systems. In addition to Recommendation ITU-R M.2101-0, a proprietary beam-nulling algorithm was used to generate the final radiation pattern. Even if the Recommendation is part of M series, nevertheless the modelling part is generally applicable to a phased array antenna used in FS application, under the assumption of no time variation. It is also noted that when implementing Recommendation ITU-R M.2101-0 discrepancy increases with increase of frequency offset and off-axis angles, as analysed in Annex 3.

The PMP system divides the azimuthal range into three sectors each one covered by one array antenna.

In each sector one phased array antenna with up to 8 beams is used to cover all the leaf sites inside. A phased array antenna contains 8 panels and in each panel there are 12 rows*16 columns antenna elements, with 8 dBi antenna gain for each single element. Hybrid beamforming is used in the simulation to steer beams from hub site to leaf sites and to perform antenna automatic alignment. Orthogonal polarizations (XPIC) are implemented on each antenna element. Parameters for the beam-nulling algorithm are not available due to the nature of the algorithm.

TDD is used in these simulations and the capacity in the results is on downlink direction, with 4:1 downlink to uplink ratio assumption (considering 5 time slots, 4 are for downlink and 1 is for uplink).

In Table 1, the significant parameters used for the simulation of the PMP system are shown:

**Table 1: System parameters for PMP performance evaluation**

| Parameter | Modulation | Value |
|---|---|---|
| e.i.r.p. | QPSK<br>64 QAM<br>256 QAM<br>1024 QAM | 56 dBm<br>53 dBm<br>50 dBm<br>50 dBm |
| SNR | QPSK<br>64 QAM<br>256 QAM<br>1024 QAM | 5 dB<br>21 dB<br>29 dB<br>36 dB |
| Noise Figure | | 8.5 dB |

Considering elevation angle defined as zero when pointing to the horizon and positive when pointing over the horizon, in both configurations taken as examples in sections 3.3.1 and 3.3.2 the range of elevation angles of the different links is limited between -1.4° and +3.3°, as it is expected also in a significant percentage of real deployment situations and is consistent with Recommendation ITU-R F.2086 [8].

The operational range of the PMP system in elevation is expected to be within ±3 degrees.

It is to be noted that in some cases (for example in mountain environment) the distribution of elevation angles could be wider than the range considered for the PMP system; nevertheless if the distribution of values around the average is within ±3 degrees the PMP system is still able to work within the defined limited elevation range because the average value can be compensated by means of mechanical tilting.

In Table 2, the system parameters relevant to antenna pattern simulation are collected.

Table 2: System parameters for PMP antenna pattern evaluation

| Parameter | Value |
|---|---|
| Panels | 8 |
| Antenna elements per panel | 12Vx16H |
| Single element gain | 8 dBi |
| Horizontal HPBW of single element | 90° |
| Vertical HPBW of single element | 56° |
| Front to back ratio | 30 dB |
| Horizontal spacing | 0.5*λ |
| Vertical spacing | [0.5-0.9]*λ |
| e.i.r.p. per panel (Note 1) | 56 dBm |
| Azimuth steering range | -60 to +60 degrees |
| Elevation steering range | -3 to +3 degrees |
| Conducted power per antenna element | 6.5 dBm |
| Array loss | 1.5 dB |
| Power back-off | 2.5 dB |
| Note 1: e.i.r.p. = 6.5 + 8 - 1.5 - 2.5 + 20 log (12x16) = 56 dBm | |

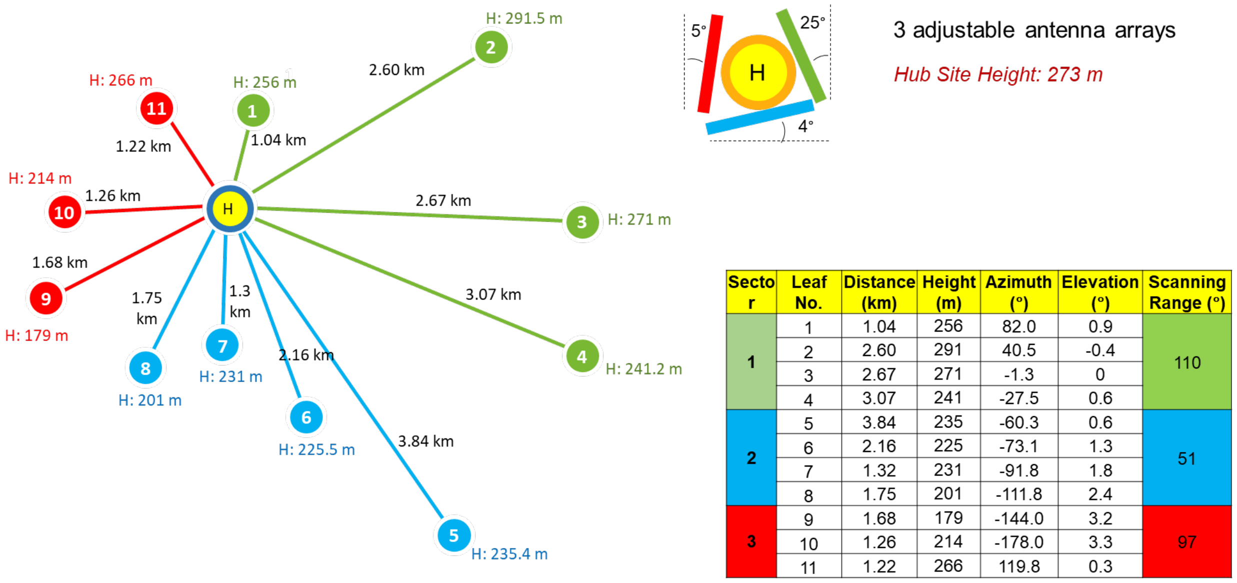
It is to be noted that the vertical spacing intended for this application is within 0.5-0.8*λ, nevertheless for sensitivity analysis the simulation range has been extended to 0.9*λ. In the two following cases, a value of 0.7*λ has been used.

Accuracy in phase and amplitude control applied to the example cases are:

- phase control quantised on 6 bits;
- amplitude control range of 10 dB in 0.5 dB steps.

### 3.3.1 Case 1: medium density site (11 links)

The system configuration in the horizontal (azimuth) plane is shown in Figure 16, where the azimuth angle is measured relative to x axis in horizontal plane and the scanning range (sector) is given by the angle between the first and the last link of a sector.

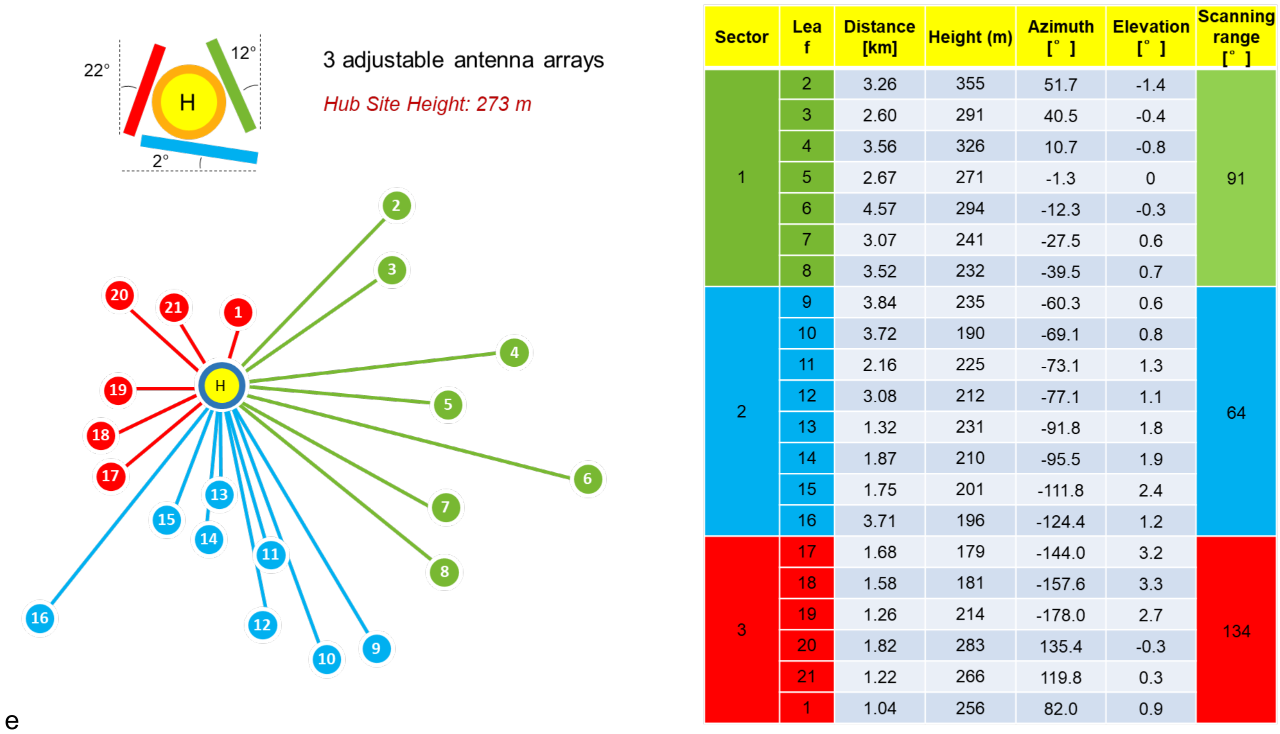


| Sector | Leaf No. | Distance (km) | Height (m) | Azimuth (°) | Elevation (°) | Scanning Range (°) |
|---|---|---|---|---|---|---|
| 1 | 1 | 1.04 | 256 | 82.0 | 0.9 | 110 |
| | 2 | 2.60 | 291 | 40.5 | -0.4 | |
| | 3 | 2.67 | 271 | -1.3 | 0 | |
| | 4 | 3.07 | 241 | -27.5 | 0.6 | |
| 2 | 5 | 3.84 | 235 | -60.3 | 0.6 | 51 |
| | 6 | 2.16 | 225 | -73.1 | 1.3 | |
| | 7 | 1.32 | 231 | -91.8 | 1.8 | |
| | 8 | 1.75 | 201 | -111.8 | 2.4 | |
| 3 | 9 | 1.68 | 179 | -144.0 | 3.2 | 97 |
| | 10 | 1.26 | 214 | -178.0 | 3.3 | |
| | 11 | 1.22 | 266 | 119.8 | 0.3 | |

Figure 16: System configuration with 11 links

### 3.3.2 Case 2: high density site (21 links)

The system configuration in the horizontal (azimuth) plane is shown in Figure 17, where the azimuth angle is measured relative to x axis in the horizontal plane and the scanning range (sector) is given by the angle between the first and the last link of a sector.



| Sector | Leaf | Distance [km] | Height (m) | Azimuth [° ] | Elevation [° ] | Scanning range [° ] |
|---|---|---|---|---|---|---|
| 1 | 2 | 3.26 | 355 | 51.7 | -1.4 | 91 |
| | 3 | 2.60 | 291 | 40.5 | -0.4 | |
| | 4 | 3.56 | 326 | 10.7 | -0.8 | |
| | 5 | 2.67 | 271 | -1.3 | 0 | |
| | 6 | 4.57 | 294 | -12.3 | -0.3 | |
| | 7 | 3.07 | 241 | -27.5 | 0.6 | |
| | 8 | 3.52 | 232 | -39.5 | 0.7 | |
| 2 | 9 | 3.84 | 235 | -60.3 | 0.6 | 64 |
| | 10 | 3.72 | 190 | -69.1 | 0.8 | |
| | 11 | 2.16 | 225 | -73.1 | 1.3 | |
| | 12 | 3.08 | 212 | -77.1 | 1.1 | |
| | 13 | 1.32 | 231 | -91.8 | 1.8 | |
| | 14 | 1.87 | 210 | -95.5 | 1.9 | |
| | 15 | 1.75 | 201 | -111.8 | 2.4 | |
| | 16 | 3.71 | 196 | -124.4 | 1.2 | |
| 3 | 17 | 1.68 | 179 | -144.0 | 3.2 | 134 |
| | 18 | 1.58 | 181 | -157.6 | 3.3 | |
| | 19 | 1.26 | 214 | -178.0 | 2.7 | |
| | 20 | 1.82 | 283 | 135.4 | -0.3 | |
| | 21 | 1.22 | 266 | 119.8 | 0.3 | |
| | 1 | 1.04 | 256 | 82.0 | 0.9 | |

e

Figure 17: System configuration with 21 links

### 3.3.3 Antenna patterns for Case 2

In order to allow a better comprehension of the behaviour of the new PMP system, the antenna patterns in the azimuth plane of the most critical sector in the high density case are provided. With reference to Figure 17, sector 2 is considered; it is constituted of 8 links (from 9th to 16th) and it is the one with narrower angles between adjacent links.

When considering antenna patterns it is worthwhile to remind that in this application they are static and not changing in time, apart from the limited drift effects due to temperature and aging applicable to every equipment. A proper automatic calibration procedure to be repeated with a due periodicity is able to counteract effectively these slow effects.

Radiation Pattern Envelopes (RPEs) from the hub to each single leaf of sector 2 are shown in Figure 18, Figure 19, Figure 20 and Figure 21, where beam-nulls are applied in the directions of the other leaves. It is worthwhile to clarify that these single leaf RPEs are just simulation entities showed for the aim of understanding the behaviour of the system, but the physical RPE which can be measured is the one coming from the superposition of all these single patterns, that is the overall sector RPE as shown in Figure 22. The simulations for the single leaves are based on both application of the model of Recommendation ITU-R M.2101-0 and proprietary beam-nulling algorithm and could therefore not be reproduced without knowledge of the dedicated proprietary beam-nulling algorithm.

The azimuth reference in the following figures is the boresight of the array antenna serving the sector.

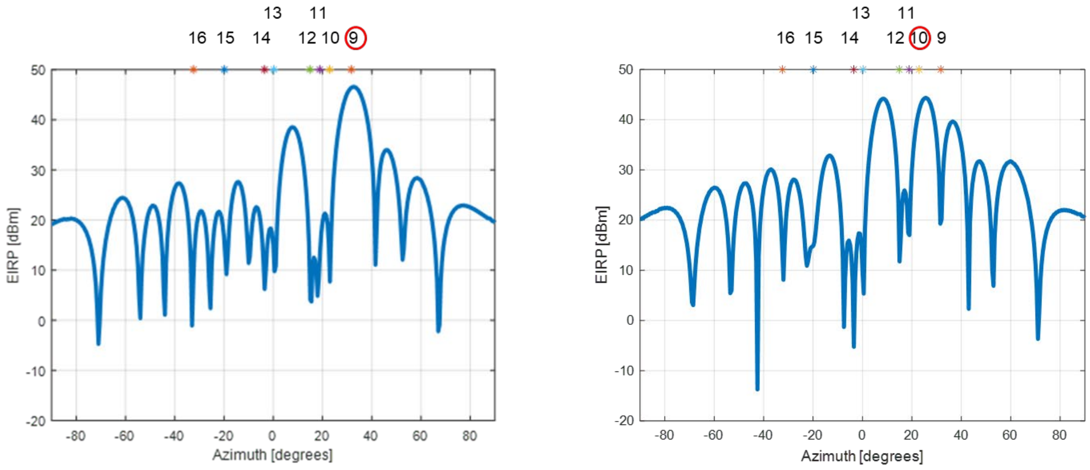


Figure 18: RPE from hub to leaves 9 and 10

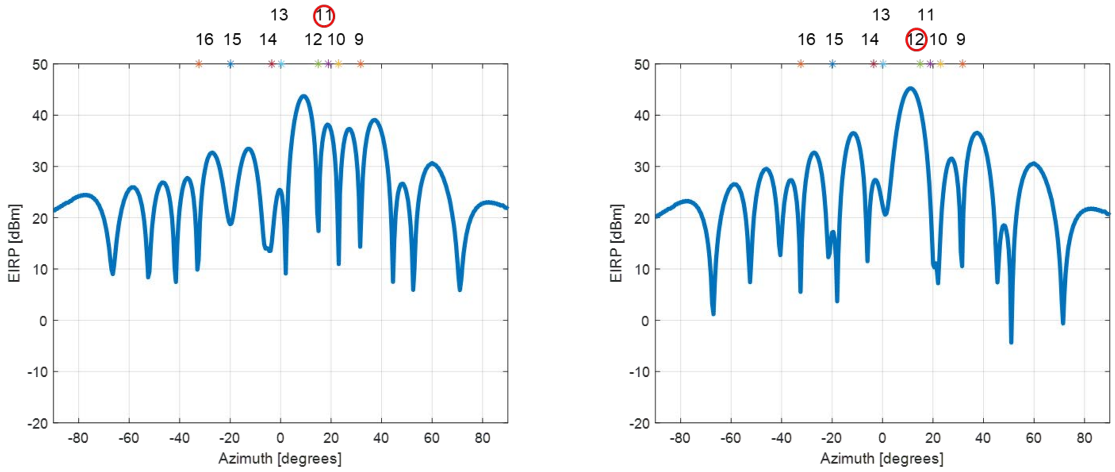


Figure 19: RPE from hub to leaves 11 and 12

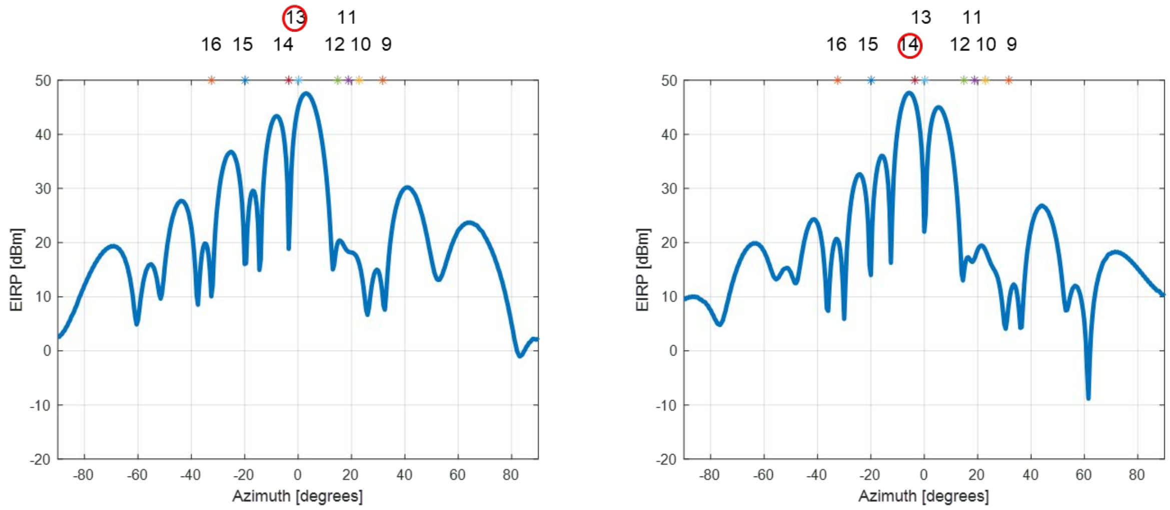


Figure 20: RPE from hub to leaves 13 and 14

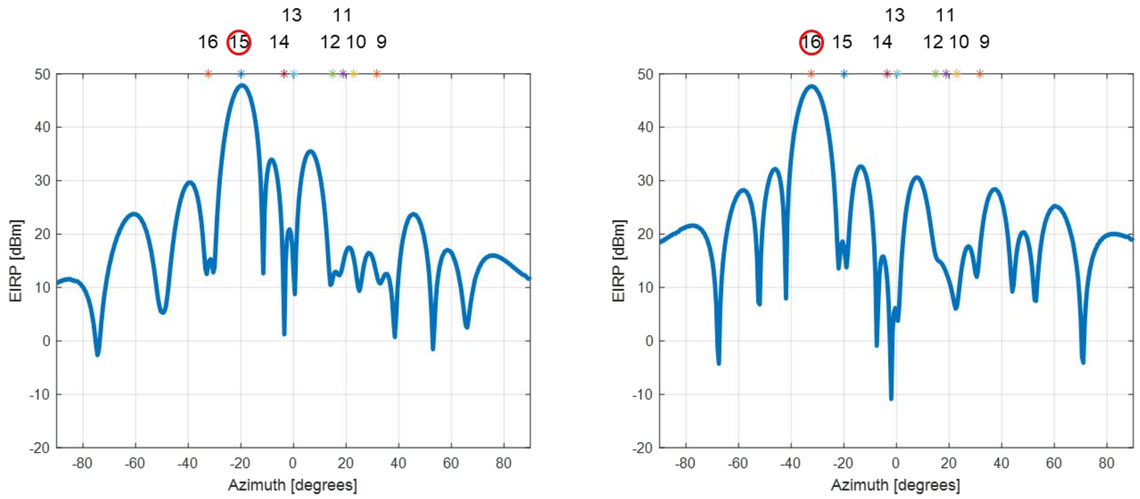


Figure 21: RPE from hub to leaves 15 and 16

The overall RPE from the hub to the sector is showed in Figure 22; it is worthwhile to note that the sector RPE is much more similar to a PMP sector pattern than to a superposition of P-P links.

Provided that the sector RPE is within current regulatory values for PMP systems, no additional interference issues are expected by the new system compared to a traditional one.

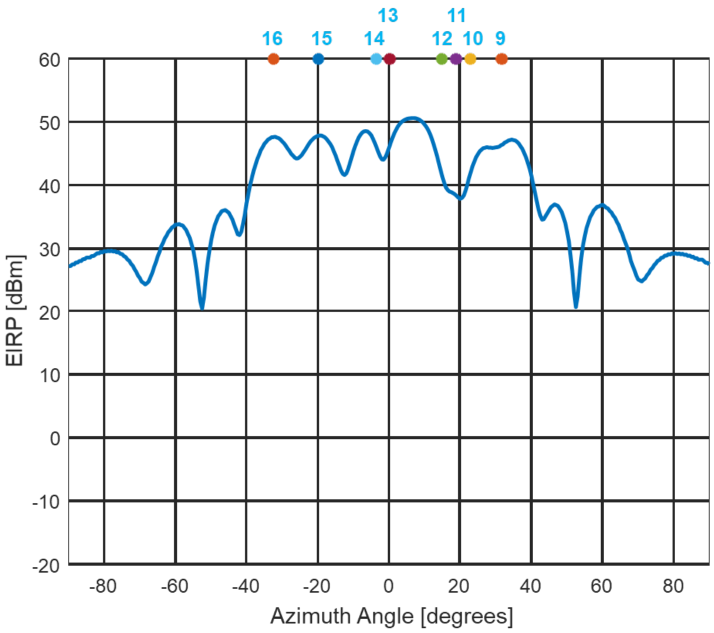


Figure 22: Overall RPE from hub to sector 2 (azimuth plane)

When looking at the overall RPE for sector 2, it can be noted that where leaves with narrow azimuth angle between them applies, a local minimum is present (see for example groups 10, 11, 12 and 13, 14). This comes from the behaviour of the system, which directs a beam towards each leaf while at the same time applying nulls in the directions of all other leaves; so in case of narrow angles the combined effect on the overall RPE is a local minimum, but the S/N over the full sector is maximised.

For comparison and further understanding it is useful to see the RPE deriving from the simple application of the model of Recommendation ITU-R M.2101-0 to the same sector without any nulling, as can be seen by a simulation coming from a different source (Figure 23 and Figure 24).

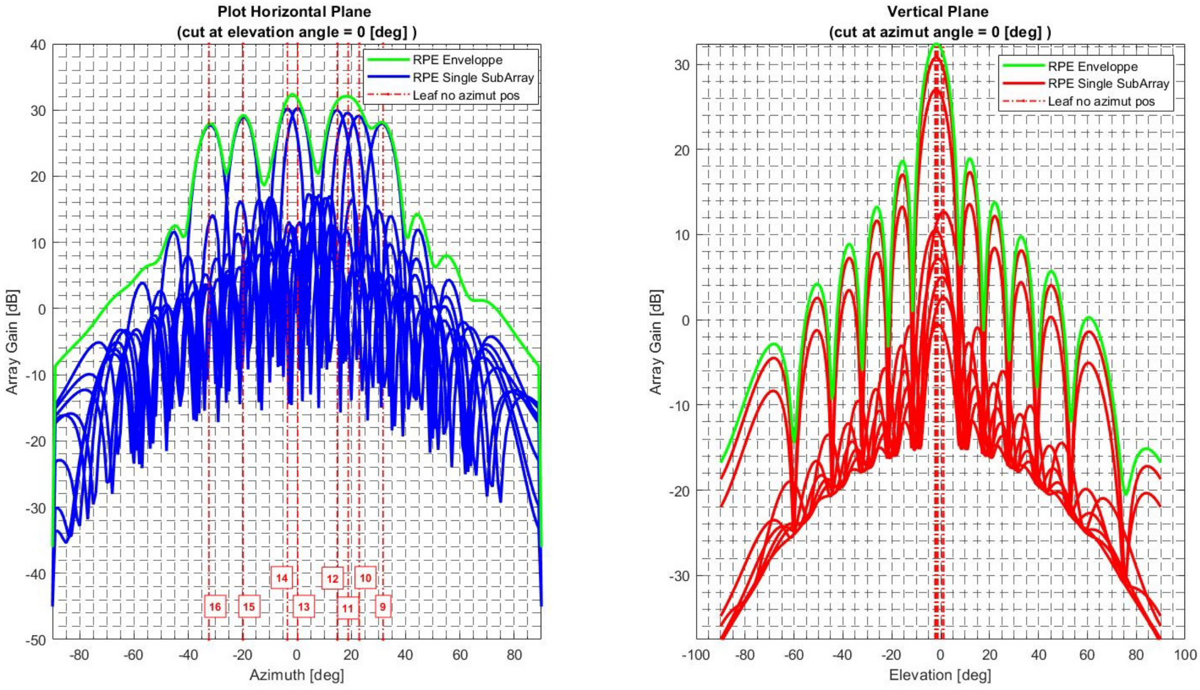


Figure 23: Overall RPE (azimuth and elevation) from hub to sector 2 without applying nulling

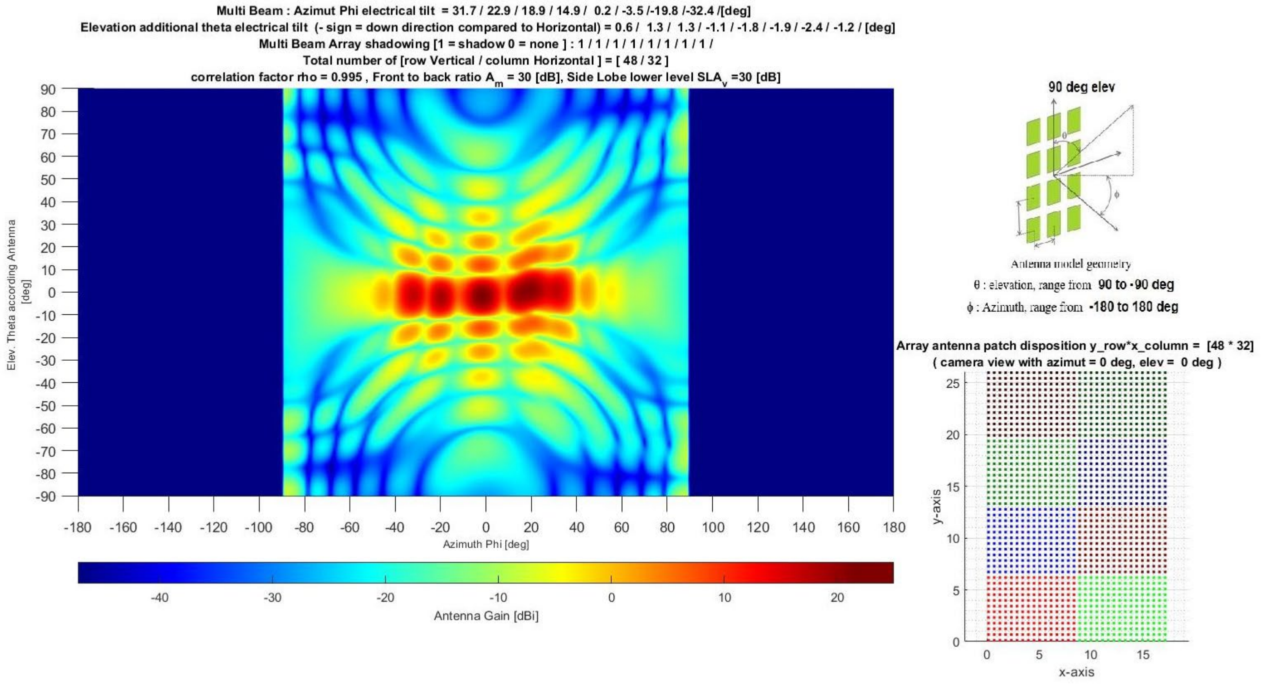


Figure 24: Overall RPE (azimuth and elevation) from hub to sector 2 without applying nulling

In this case, the peaks are directed towards each single leaf as can be expected by applying the Recommendation ITU-R M.2101-0 [7] model alone without beam-nulling algorithm, but the S/N of the whole sector would not be maximised.

### 3.3.4 Conclusions of simulations

The combination of beamforming and interference cancellation technologies used in the new PMP system allows to achieve the coverage of an area surrounding a hub site using just one frequency, even in high density deployment scenarios.

## 3.4 ADDITIONAL TECHNICAL CONSIDERATIONS

In order to deploy a new system in a band, it is necessary to consider the sharing with other systems occupying the same band and compatibility with systems in the nearby bands.

In this sense, the compliance of the RPE of the new system with the ETSI emission masks as for EN 302 326-3 [9] in both azimuth and elevation represents an effective indication that no further emissions are expected with respect to a traditional system in the space domain. However, RPE is not the only parameter to be considered for sharing studies.

The system described here is operating with 224 MHz channels. It may be noted that the merge of 112 MHz channels to create 224 MHz channels was based on a point-to-point analysis (see ECC Report 319 [16]). However, ERC Recommendation T/R 13-02 [4] does not have any limitation what type of FS link may use these wide channels. Since the analysis in ECC Report 319 cannot be reproduced for PMP systems, due to the absence of a relevant ETSI standard, care is needed when studying unwanted emissions from PMP systems operating with 224 MHz channels.

For what regards the frequency domain, compliance to limits on unwanted emissions according to ERC Recommendation 74-01 [10] is required in order to assess that no additional interference is expected with respect to existing systems.

### 3.4.1 Considerations about grating lobes

It is well known that when considering phased array antenna systems with the aim to beam-form the radiated pattern in some specific conditions grating lobes could appear, where a grating lobe is defined as a lobe, other than the main lobe, produced by an array antenna when the element spacing is sufficiently large to permit the in-phase addition of radiating fields in a direction different from the wanted one.

Different factors explain the occurrence of these high lobes in antenna array:

1 The element spacing in horizontal and vertical directions.

1 The phase of the excitation signal at each radiating element, which determine the beam-steering.

In particular, three situations can be distinguished depending on the value of the d/λ ratio:

a) 1) d/λ ≤ 0.5. In this case no grating lobe is generated. This is the case in the considered PMP system in the azimuth plane, due to the horizontal element spacing.

b) 2) 0.5 < d/λ < 1. In this case grating lobes can appear in the radiation pattern depending on the steering angle with respect to the boresight direction (that is the direction orthogonal to the array plane). It can be demonstrated [11] that for a steering angle less than θmax no grating lobes will be present on the condition that:

$$\frac{d}{\lambda} < \frac{1}{(1 + |sin\theta\mathrm{max}|)}$$

For example when considering f=28 GHz and θmax=3° no grating lobes are expected if d/λ < 0.95. This is the case in the considered PMP system in elevation due to the vertical element spacing.

c) 3) d/λ ≥ 1. In this case grating lobes appear even without any beam-steering, which is when the main beam is directed in the boresight direction.

So from the theoretical point of view no grating lobe can be expected within the parameter range considered in Table 2 for the PMP system under description.

It is to be noted that a limited accuracy on amplitude and phase controls of the array could have an impact in the appearance of grating lobes in cases when parameters, in particular vertical spacing and steering angle, are near the critical edge of their range.

### 3.4.2 Compliance of RPE with ETSI antenna masks (space domain)

ETSI EN 302 326-3 [9] indicates the limits that a PMP system shall comply with in terms of RPE, as reported in the following Figure 25 (azimuth section) and Figure 26 (elevation section).

The RPE of the PMP system described in this Report is consistent with the sectored single beam case in ETSI EN 302 326-3 since it is radiating over a defined angular sector in the azimuth plane. Instead the sectored multi-beam case is dealing with systems radiating over several defined angular sectors in the azimuth plane, which is not the case of the PMP system described in this Report.

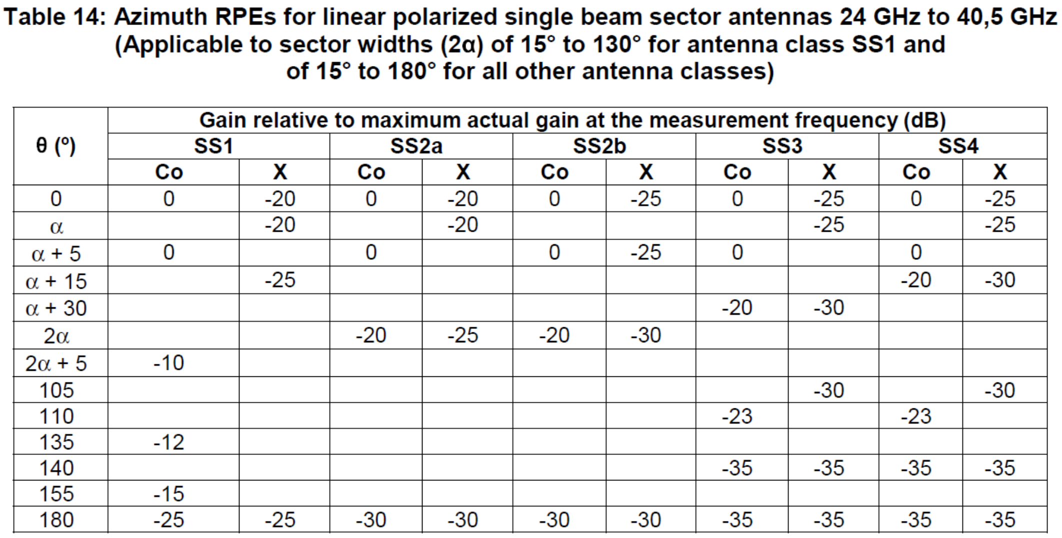


**Table 14: Azimuth RPEs for linear polarized single beam sector antennas 24 GHz to 40,5 GHz (Applicable to sector widths (2α) of 15° to 130° for antenna class SS1 and of 15° to 180° for all other antenna classes)**

| θ (°) | Gain relative to maximum actual gain at the measurement frequency (dB) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SS1 | | SS2a | | SS2b | | SS3 | | SS4 | |
| | Co | X | Co | X | Co | X | Co | X | Co | X |
| 0 | 0 | -20 | 0 | -20 | 0 | -25 | 0 | -25 | 0 | -25 |
| α | | -20 | | -20 | | | | -25 | | -25 |
| α + 5 | 0 | | 0 | | 0 | -25 | 0 | | 0 | |
| α + 15 | | -25 | | | | | | | -20 | -30 |
| α + 30 | | | | | | | -20 | -30 | | |
| 2α | | | -20 | -25 | -20 | -30 | | | | |
| 2α + 5 | -10 | | | | | | | | | |
| 105 | | | | | | | | -30 | | -30 |
| 110 | | | | | | | -23 | | -23 | |
| 135 | -12 | | | | | | | | | |
| 140 | | | | | | | -35 | -35 | -35 | -35 |
| 155 | -15 | | | | | | | | | |
| 180 | -25 | -25 | -30 | -30 | -30 | -30 | -35 | -35 | -35 | -35 |

**Figure 25: ETSI limits for PMP emission in azimuth**

In this case, sector width of 120° and antenna class SS2b are considered (the higher the class number, the stricter the emission requirements).

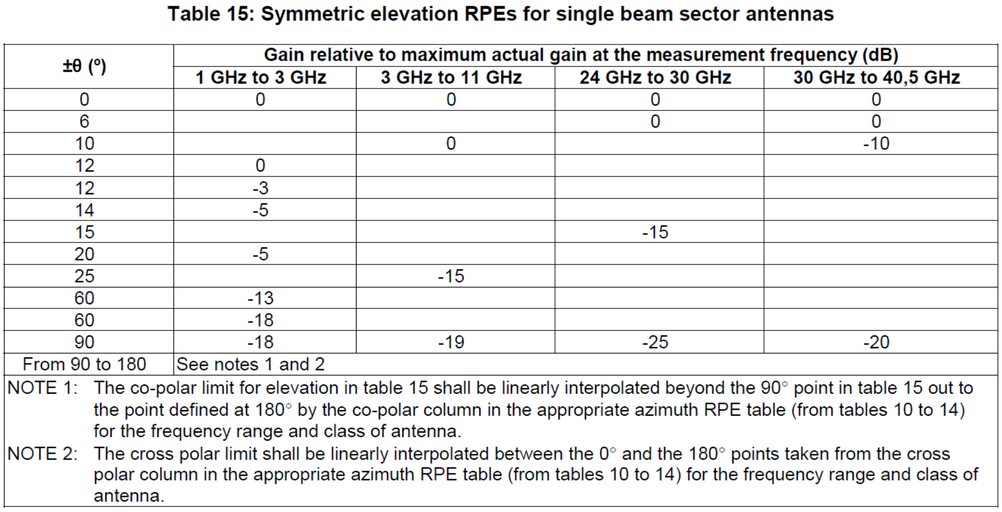


**Table 15: Symmetric elevation RPEs for single beam sector antennas**

| ±θ (°) | Gain relative to maximum actual gain at the measurement frequency (dB) | | | |
|---|---|---|---|---|
| | 1 GHz to 3 GHz | 3 GHz to 11 GHz | 24 GHz to 30 GHz | 30 GHz to 40,5 GHz |
| 0 | 0 | 0 | 0 | 0 |
| 6 | | | 0 | 0 |
| 10 | | 0 | | -10 |
| 12 | 0 | | | |
| 12 | -3 | | | |
| 14 | -5 | | | |
| 15 | | | -15 | |
| 20 | -5 | | | |
| 25 | | -15 | | |
| 60 | -13 | | | |
| 60 | -18 | | | |
| 90 | -18 | -19 | -25 | -20 |
| From 90 to 180 | See notes 1 and 2 | | | |

NOTE 1: The co-polar limit for elevation in table 15 shall be linearly interpolated beyond the 90° point in table 15 out to the point defined at 180° by the co-polar column in the appropriate azimuth RPE table (from tables 10 to 14) for the frequency range and class of antenna.

NOTE 2: The cross polar limit shall be linearly interpolated between the 0° and the 180° points taken from the cross polar column in the appropriate azimuth RPE table (from tables 10 to 14) for the frequency range and class of antenna.

**Figure 26: ETSI limits for PMP emission in elevation**

When selecting the proper ETSI mask to be applied to the system RPE to verify the compliance, the operating frequency is to be considered.

A sensitivity analysis of compliance for a PMP system at a particular mmW band is reported in Annex 2 with respect to antenna element spacing and to operating frequency within the band. In both cases, the system is compliant with the relevant ETSI mask when the parameter is changing within the interval of interest. The co-polar case is considered.

### 3.4.3 Compliance of unwanted emission in the spurious range (frequency domain)

For what regards the unwanted emissions, the system has to comply with ERC Recommendation 74-01 [10]; in particular, this Recommendation deals with the Fixed Service in its Annex 1 and Active Antenna Systems (AAS) are introduced in "considering q, Note 1".

Even if in current version of ERC Recommendation 74-01 [10] no AAS is considered within FS part, nevertheless a significant reference can be found in ERC Recommendation 74-01, annex 2, table 6, note 6 in which Total Radiated Power (TRP) is defined as the proper metric for determination of unwanted emissions in case of AAS system.

The spurious limit to be respected by a FS system, which is provided in ERC Recommendation 74-01, annex 1, Table 3 [10] should be checked, in case of non-detachable, integrated antenna taking into account that the TRP value is to be considered, including also the loss in the antenna. The limit for both central and terminal stations for carrier frequencies higher than 21.2 GHz (applicable to this Report) is -30 dBm/MHz.

The main implication of a system with integrated antenna is that the measurement of spurious emission is not anymore a conducted measurement at the antenna connector, which is not available, but a radiated one to be done in a controlled environment such as an anechoic chamber.

In Annex 2, Table 6, Note 6 of ERC Recommendation 74-01, a description of the measurement procedure for spurious emission as TRP in AAS systems is provided.

In any case, the issue of measuring the unwanted emission of new systems with non-detachable, integrated antenna is currently under consideration at different standardization and regulatory bodies, as ETSI (ATTM TM4) and ECC Project Team SE21). A stable reference is ETSI TS 138 141-2 [12] which defines methods for radiated testing of AAS systems, based on 3GPP TS 38.141-2 [13].

However in this context as well it is worthwhile to remind that in this PMP application, once the system has been configured (or re-configured in case of addition of new leaves), the antenna pattern is static and not changing in time, apart from the limited drift effects due to temperature and aging applicable to every equipment. A proper automatic calibration procedure to be repeated with a due periodicity is able to counteract effectively these slow effects.

## 3.5 MEASUREMENTS

Preliminary measurements have been conducted on a prototype PMP system in order to compare them to the simulation results; they are described in Annex 3.

These preliminary measurements show two important features:

1. There is very good correspondence between simulations and measurements.
2. The measurements are compliant with the required ETSI masks for PMP systems both in azimuth and elevation.

# 4 CONCLUSIONS

This Report describes a Point-to-Multipoint (PMP) system intended to operate within Fixed Service (FS) for backhaul applications which implements a star topology by leveraging on an active antenna (AAS) configured to synthetise multiple beams, connecting the central station to several stations. The Report is a technical description of the PMP system which includes the key technologies (beamforming and interference cancellation techniques) and some possible deployment cases (low density site and high density site).

This Report contains simulations and measurements made using available prototype in an attempt to show the feasibility of the concept, including compliance with relevant standards and requirements for the fixed service. In particular, compliance with the relevant ETSI emission masks both in azimuth and elevation is assessed for co-polar signal (see section 3.4.2), including a sensitivity analysis relative to operating frequency and antenna element spacing. Applicability of ERC Recommendation 74-01 [10] for compliance with unwanted emission limits of the system is assessed as well (see section 3.4.3). At the time of developing this Report no ETSI standard for Fixed Service equipment properly takes into account the specificity of the active antennas considered, where no antenna connector is available.

This Report does not contain sharing or compatibility studies both within the FS and with other services that may be used as the basis for regulatory measures and equipment harmonisation in a specific band. Furthermore, it does not contain any information on the actual Out of Band (OoB) emissions from the PMP system using AAS and as such it does not include verification or assessment of quantity or quality of unwanted emissions.

This Report is not band-specific, and it considers a PMP system using AAS in FS bands above 27.5 GHz; therefore the concept could be applied to any other mmW frequencies. It is to be noted that the current PMP ETSI standard considers only frequency bands up to 43.5 GHz.

It is important to highlight that, even if the proposed new PMP system uses some technologies widely used by mobile networks, the system can only fall, in all aspects, within FS category since no mobility is present or foreseen neither at the central station nor at the connected fixed stations. This applies to the antenna pattern as well which is in general static within a certain tolerance due to e.g. temperature and not changing in time, once the PMP system has been configured (or re-configured).

# ANNEX 1: SYSTEM CAPACITIES OBTAINED WITH A PMP SYSTEM

This Annex describes an example of estimation of capacity in 28 GHz band that can be obtained by PMP system with the two use cases described in section 3.3.

This system capacity analysis does not indicate that 28 GHz is a preferred band for such systems and such analysis can be undertaken at any other mmWave frequency taking into account appropriate propagation losses and other parameters.

In order to perform an analysis the following conditions are assumed:

- Atmospheric parameters: Pressure=1013.25 hPa; Temperature=15° C; Water vapour density=7.5 g/m3;
- Rain rate @0.01% of time: K rain zone, 47 mm/h for 0.01% of time according to Recommendation ITU-R P.837-7 [6];
- Propagation model: Recommendation ITU-R P.530-16 [17];
- Centre frequency for PMP: 28 GHz.

## A1.1 CASE 1: MEDIUM DENSITY SITE (11 LINKS)

Per each link a 200 MHz signal bandwidth within a 224 MHz channel and XPIC are used.

At the leaf site, an ordinary parabolic antenna is considered (G=42 dBi, d=60cm) but also an antenna array could be used.

The system simulation has been done at fixed availabilities. The targets that the system has to achieve per each leaf are:

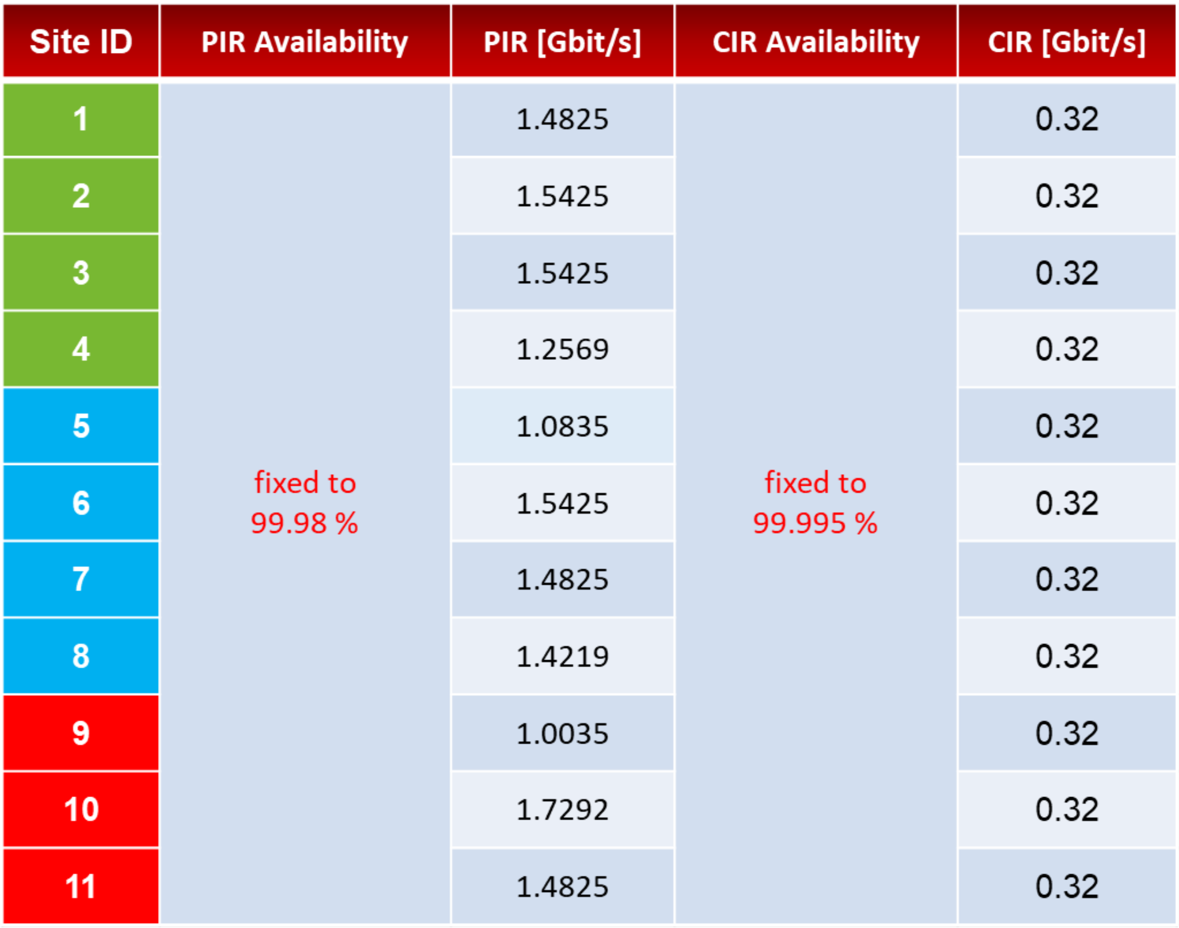
- PIR (Peak Information Rate): at least 1 Gb/s @ 99.98% availability;
- CIR (Committed Information Rate): 0.3 Gb/s @ 99.995% availability.

In ideal propagation conditions (clear sky, no interference), considering an ACM efficiency of 0.8 and the TDD ratio of 4/5, the maximum theoretical throughput per link is 1.5 Gb/s at 64 QAM, 2 Gb/s at 256 QAM and 2.5 Gb/s at 1024 QAM.

In order to achieve higher throughput either more channels are to be aggregated (where available) or wider channels have to be used (where available).

The simulation results are shown in Table 3.

Table 3: System performance at fixed availabilities (11 leaves) without interference cancellation



| Site ID | PIR Availability | PIR [Gbit/s] | CIR Availability | CIR [Gbit/s] |
|---|---|---|---|---|
| 1 | fixed to 99.98 % | 1.4825 | fixed to 99.995 % | 0.32 |
| 2 | | 1.5425 | | 0.32 |
| 3 | | 1.5425 | | 0.32 |
| 4 | | 1.2569 | | 0.32 |
| 5 | | 1.0835 | | 0.32 |
| 6 | | 1.5425 | | 0.32 |
| 7 | | 1.4825 | | 0.32 |
| 8 | | 1.4219 | | 0.32 |
| 9 | | 1.0035 | | 0.32 |
| 10 | | 1.7292 | | 0.32 |
| 11 | | 1.4825 | | 0.32 |

As it can be seen, the system is able to satisfy the requirements at all leaves.

### A1.2 CASE 2: HIGH DENSITY SITE (21 LINKS)

Per each link a 200 MHz signal bandwidth within a 224 MHz channel and XPIC are used.

At the leaf site, an ordinary parabolic antenna is considered (G=42 dBi, d=60 cm) but also an antenna array could be used.

The system simulation has been done at fixed availabilities. The targets that the system has to achieve per each leaf are:

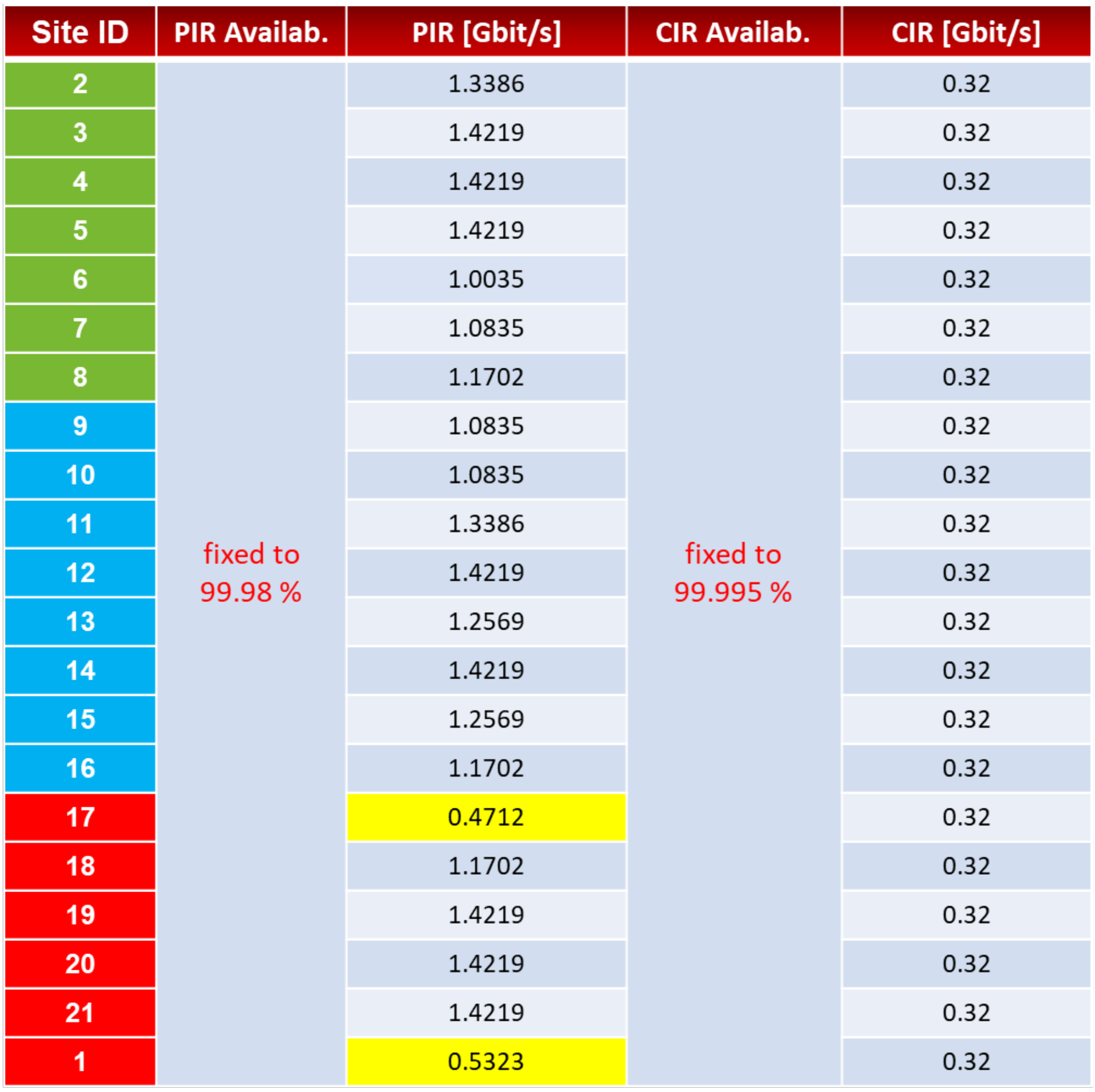
- PIR (Peak Information Rate): at least 1 Gb/s @ 99.98% availability;
- CIR (Committed Information Rate): 0.3 Gb/s @ 99.995% availability.

In ideal propagation conditions (clear sky, no interference), considering an ACM efficiency of 0.8 and the TDD ratio of 4/5, the maximum theoretical throughput per link is 1.5 Gb/s at 64 QAM, 2 Gb/s at 256 QAM and 2.5 Gb/s at 1024 QAM.

In order to achieve higher throughput either more channels are to be aggregated (where available) or wider channels have to be used (where available).

The simulation results are shown in Table 4.

Table 4: System performance at fixed availabilities (21 leaves) without interference cancellation

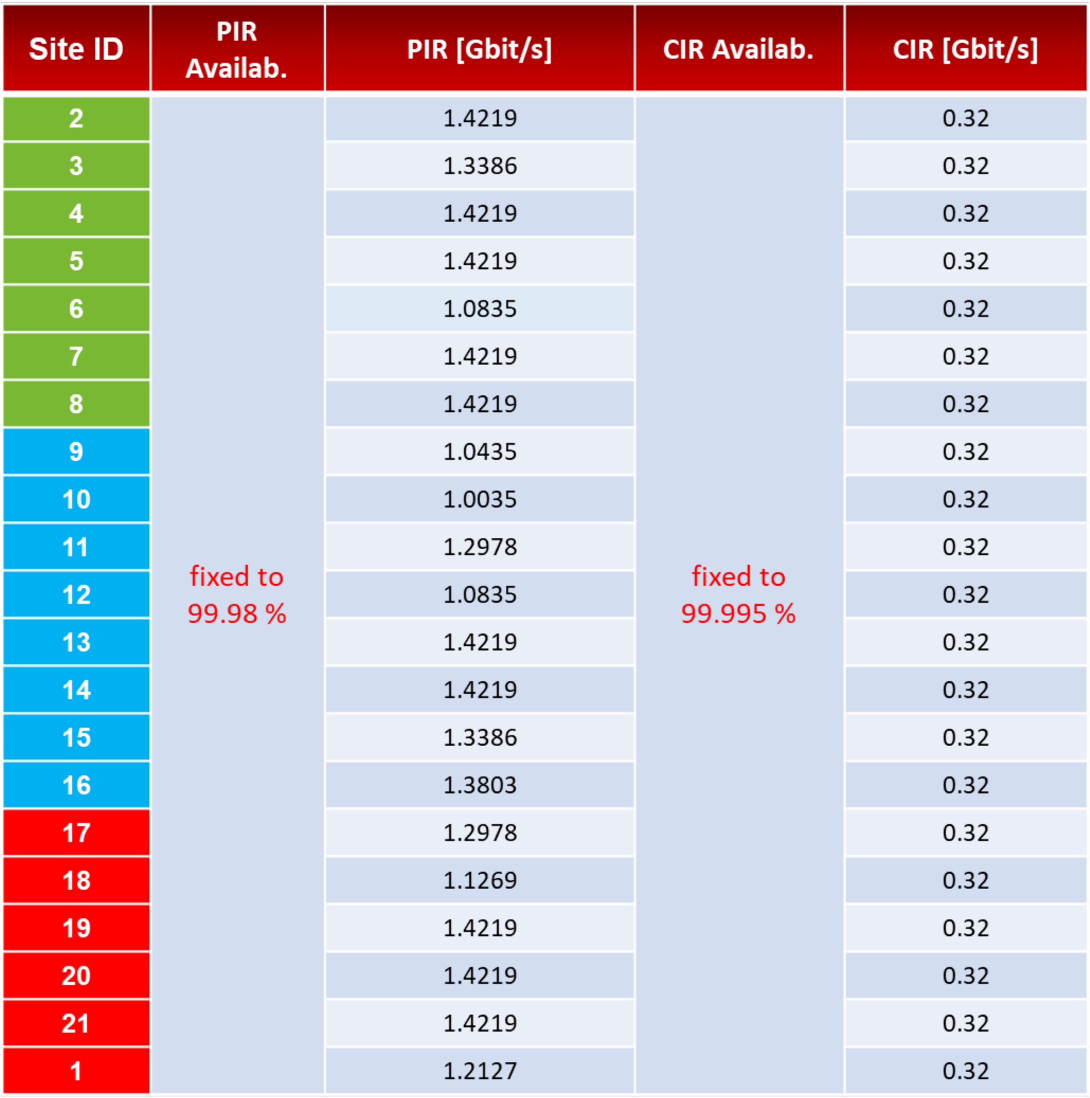


| Site ID | PIR Availab. | PIR [Gbit/s] | CIR Availab. | CIR [Gbit/s] |
|---|---|---|---|---|
| 2 | fixed to 99.98 % | 1.3386 | fixed to 99.995 % | 0.32 |
| 3 | | 1.4219 | | 0.32 |
| 4 | | 1.4219 | | 0.32 |
| 5 | | 1.4219 | | 0.32 |
| 6 | | 1.0035 | | 0.32 |
| 7 | | 1.0835 | | 0.32 |
| 8 | | 1.1702 | | 0.32 |
| 9 | | 1.0835 | | 0.32 |
| 10 | | 1.0835 | | 0.32 |
| 11 | | 1.3386 | | 0.32 |
| 12 | | 1.4219 | | 0.32 |
| 13 | | 1.2569 | | 0.32 |
| 14 | | 1.4219 | | 0.32 |
| 15 | | 1.2569 | | 0.32 |
| 16 | | 1.1702 | | 0.32 |
| 17 | | 0.4712 | | 0.32 |
| 18 | | 1.1702 | | 0.32 |
| 19 | | 1.4219 | | 0.32 |
| 20 | | 1.4219 | | 0.32 |
| 21 | | 1.4219 | | 0.32 |
| 1 | | 0.5323 | | 0.32 |

As it can be seen, the system is able to satisfy the requirements at all leaves but two, for which a proper intra-system interference handling is to be considered, such as beam-nulling and interference cancellation technologies.

By applying interference cancellation the simulation results are according to Table 5.

Table 5: System performance at fixed availabilities (21 leaves) with interference cancellation



| Site ID | PIR Availab. | PIR [Gbit/s] | CIR Availab. | CIR [Gbit/s] |
|---|---|---|---|---|
| 2 | fixed to 99.98 % | 1.4219 | fixed to 99.995 % | 0.32 |
| 3 | | 1.3386 | | 0.32 |
| 4 | | 1.4219 | | 0.32 |
| 5 | | 1.4219 | | 0.32 |
| 6 | | 1.0835 | | 0.32 |
| 7 | | 1.4219 | | 0.32 |
| 8 | | 1.4219 | | 0.32 |
| 9 | | 1.0435 | | 0.32 |
| 10 | | 1.0035 | | 0.32 |
| 11 | | 1.2978 | | 0.32 |
| 12 | | 1.0835 | | 0.32 |
| 13 | | 1.4219 | | 0.32 |
| 14 | | 1.4219 | | 0.32 |
| 15 | | 1.3386 | | 0.32 |
| 16 | | 1.3803 | | 0.32 |
| 17 | | 1.2978 | | 0.32 |
| 18 | | 1.1269 | | 0.32 |
| 19 | | 1.4219 | | 0.32 |
| 20 | | 1.4219 | | 0.32 |
| 21 | | 1.4219 | | 0.32 |
| 1 | | 1.2127 | | 0.32 |

In the case of high density site, the advantage of employing inter-sector interference cancellation techniques is evident.

# ANNEX 2: SENSITIVITY ANALYSIS OF RPE OF A PMP SYSTEM

This annex describes the sensitivity analysis of the RPE of a PMP compared to its own ETSI EN 302 326-3 [9] RPE mask considering:

- antenna element spacing;
- operating frequency in the band;
- RPE masks for 24 GHz to 40.3 GHz band in azimuth and for 24 GHz to 30 GHz in elevation;
- co-polar signal;
- within limited elevation of PMP system [-3…+3] degrees.

The sensitivity analysis conducted using Recommendation ITU-R M.2101-0 and beam-nulling algorithm is frequency agnostic.

This analysis does not indicate any preference towards a specific band.

## A2.1 SENSITIVITY ANALYSIS OF RPE WITH RESPECT TO ANTENNA ELEMENT SPACING

With reference to the most demanding case of 21 leaves (see Figure 17) and to the most critical sector 2, the resulting RPEs for azimuth and elevation as obtained by simulations are shown in Figure 27 and Figure 28, where:

- in azimuth the RPE is a horizontal section of the total RPE emitted by the hub;
- in elevation the RPEs are vertical sections in the directions of each single leaf of the sector of the total RPE emitted by the hub;
- the ratio between vertical element distancing and wavelength dV/λ is varied in steps of 0.1 in the range 0.6 (blue), 0.7 (brown), 0.8 (orange) and 0.9 (violet).

It is worthwhile to note that in the simulations the reference coordinate system of Recommendation ITU-R M.2101-0 has been used, where in particular elevation varies between zero on the vertical up direction, 90° on the horizontal plane and 180° in the vertical down direction and azimuth is defined with respect to the boresight of the antenna.

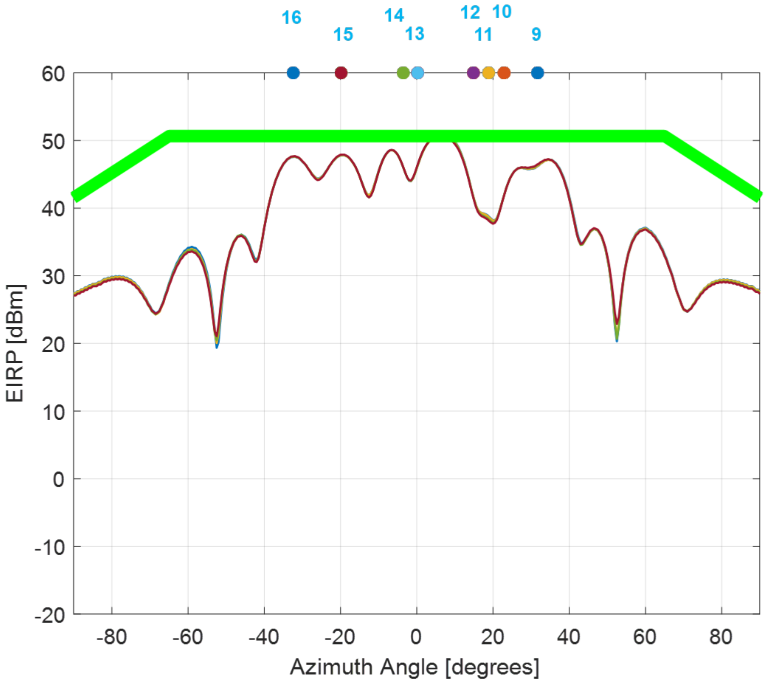


Figure 27: PMP RPE horizontal section versus ETSI PMP mask SS2b in azimuth

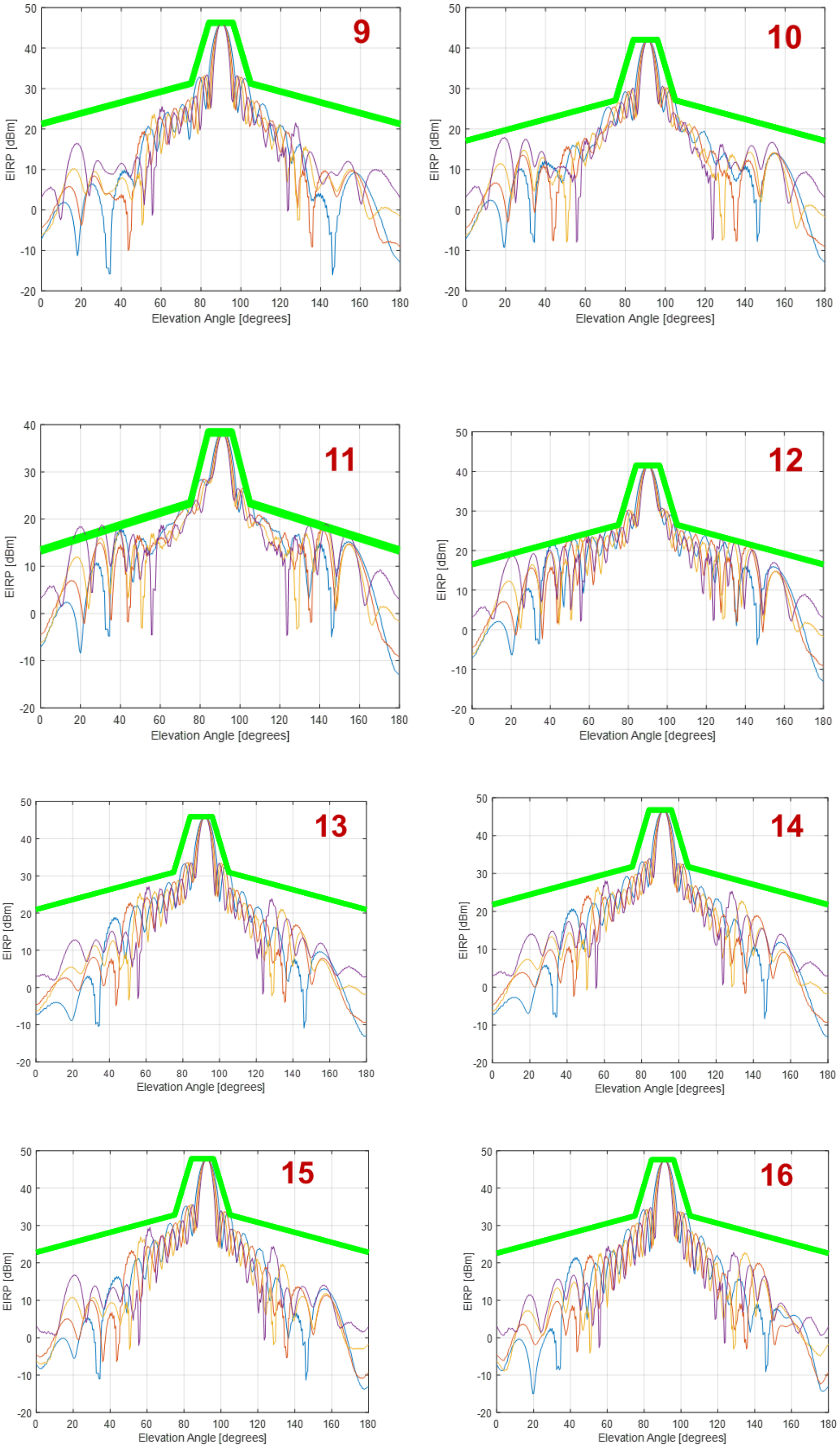


Figure 28: PMP RPE vertical sections at max beams versus ETSI PMP mask in elevation for different values of dV/λ (0.6 blue, 0.7 brown, 0.8 orange and 0.9 violet)

It is important to highlight that in Figure 28 and Figure 29 some sections of the full three-dimensional RPE are represented, where the elevation sections, even if taken in the directions of the peaks of the beams, do contain the contributions of all beams.

Whilst in the azimuth plane the dV/λ ratio is not influencing the pattern, in elevation the impact of lateral lobes is growing with the parameter; nevertheless only when dV/λ = 0.9 there is a violation of the ETSI mask.

As it can be seen from the graphs shown in Figure 28 and Figure 29 , within the range of elevation (between -3 and + 3 degrees) and of vertical distancing (dV/λ ≤ 0.8) considered for the application no additional emission with respect to a traditional PMP system is expected in both azimuth and elevation.

## A2.2 SENSITIVITY ANALYSIS OF RPE WITH RESPECT TO OPERATING FREQUENCY

Even once the system RPE compliance with ETSI mask is verified at mid band, it remains to be assessed that the system is consistent with the masks also when varying the frequency to the extremes of the operating band, as it is required in ETSI conformance testing procedures.

In Figure 29 and Figure 30, the variation of RPE when going from 27.5 (blue) to 29.5 (red) GHz is shown.

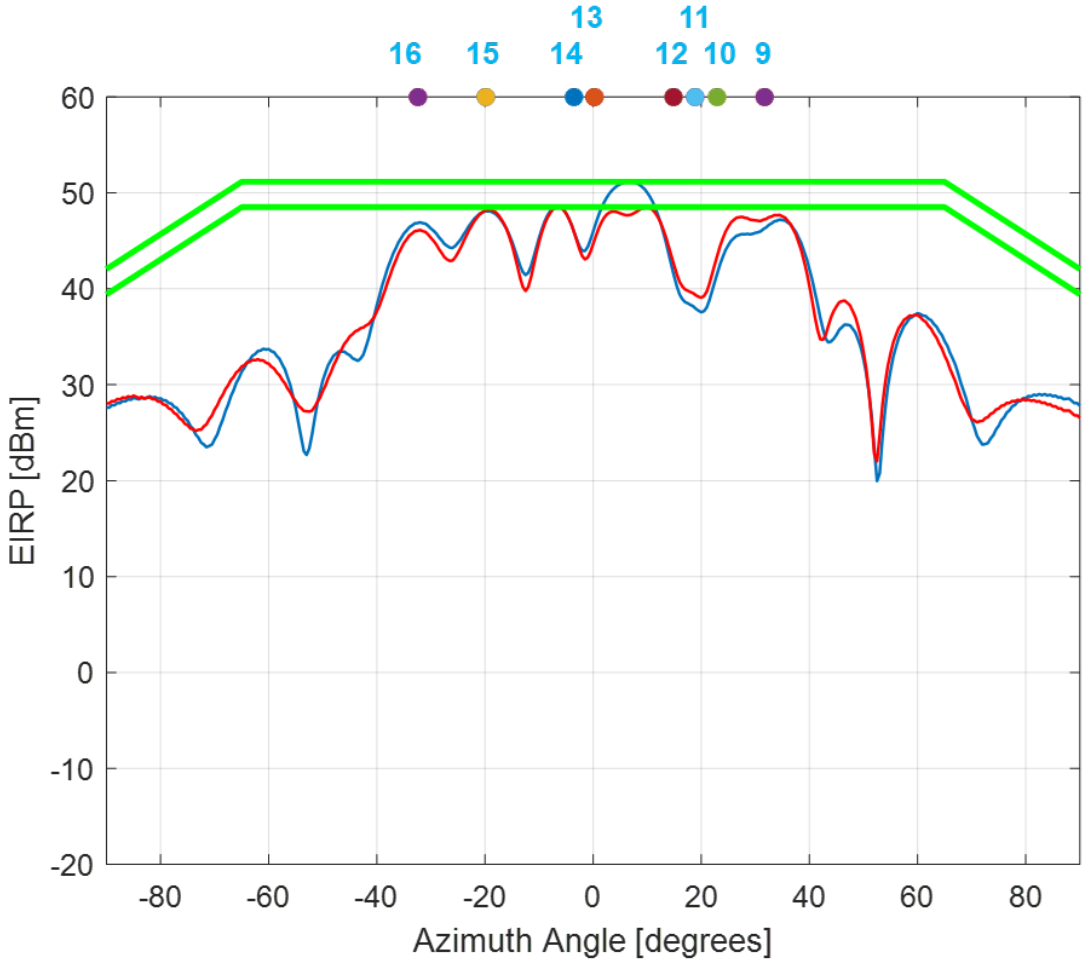


Figure 29: PMP RPE horizontal section versus ETSI PMP mask SS2b in azimuth for different frequencies (27.5 GHz red; 29.5 GHz blue)

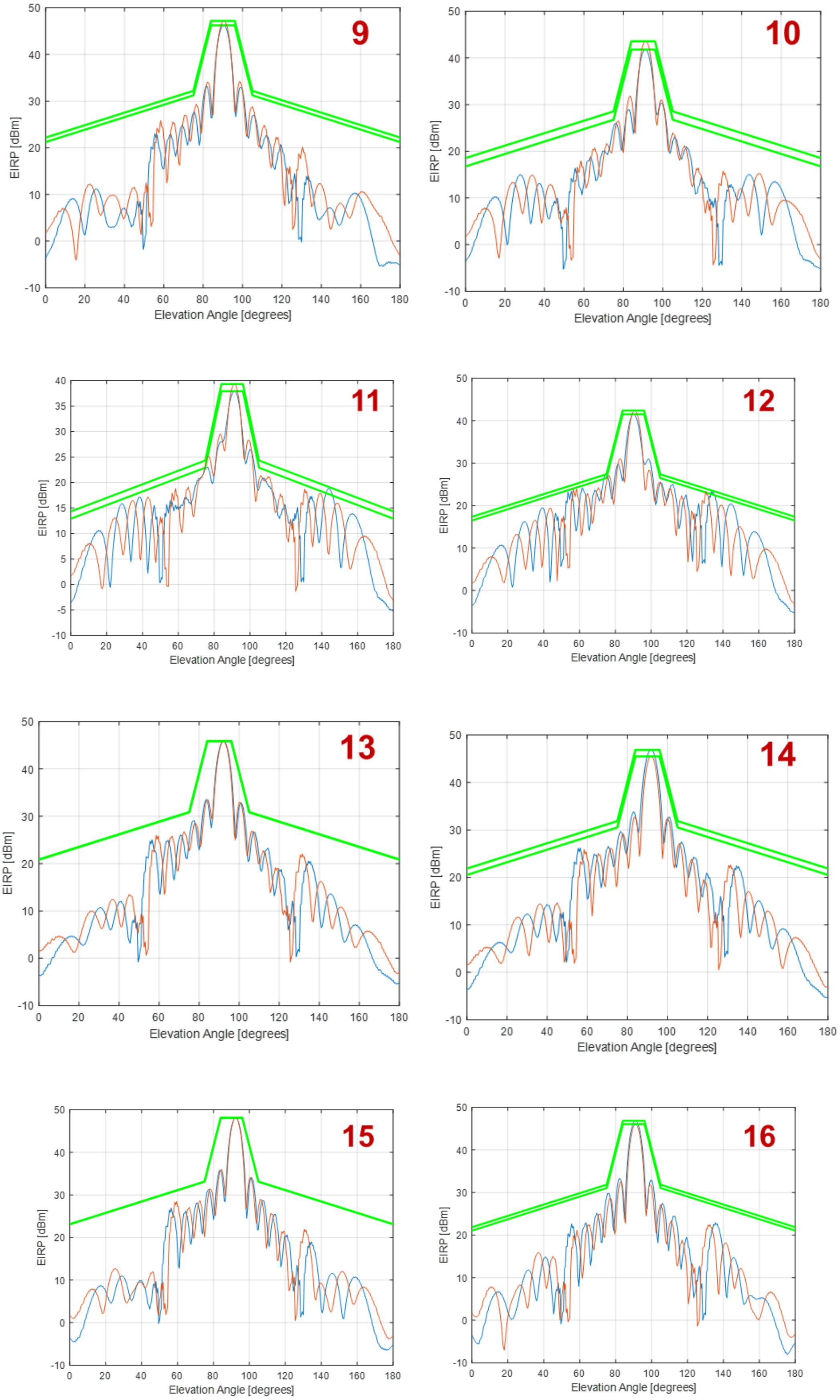


Figure 30: PMP RPE vertical sections at max beams versus ETSI PMP mask in elevation for different frequencies (27.5 GHz red; 29.5 GHz blue)

At least two relevant points can be noted:

- the maximum e.i.r.p. is slightly changing with frequency as expected (and the ETSI mask, being a relative one, is shifted accordingly);
- no additional emission with respect to a traditional PMP system is expected in both azimuth and elevation within the whole operating band.

It is to be noted also that the working frequency of the system is not really reaching the extremes of the band because on both sides there are the reserved segments for FSS, which gives additional margin to the assessment.

# ANNEX 3: MEASUREMENTS ON A PROTOTYPE PMP SYSTEM

Some preliminary measurements on a prototype PMP system are reported here for comparison with the simulated results and with the ETSI EN 302 326-3 [9] masks.

In Figure 31, the test setup in anechoic chamber is reported according to ETSI TS 138 141-2 [12].

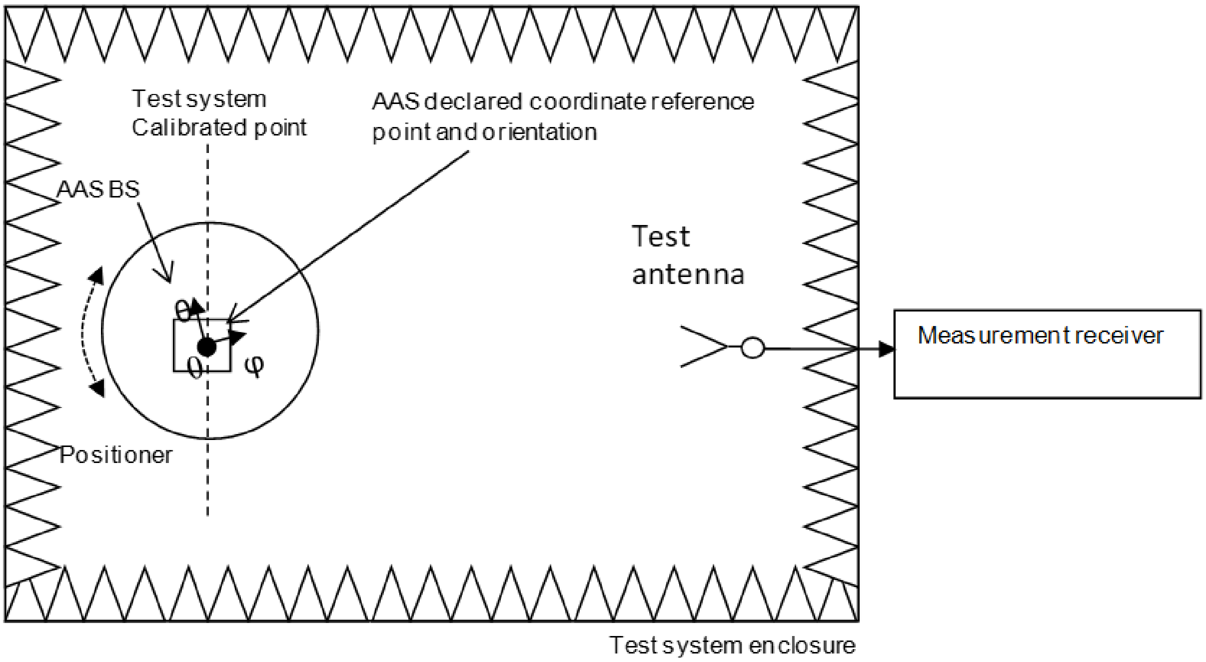


Figure 31: Test setup in anechoic chamber

The measurements on the prototype are done at 28 GHz and make use of 7 beams, oriented in azimuthal plane at -37.5°, -21.5°, -7°, 0°, 7.5°, 22.5°, 38.5°.

Being the prototype under development, the available measurements are with one less beam with respect to the simulations; nevertheless the comparison between simulations and measurements maintains its significance and value without any loss of generality.

In Figure 32, the azimuth section of the RPE is shown with reference to azimuth ETSI mask for PMP systems, where the RPE coming from all 7 beams at the same time is in brown. Also the single patterns measured when activating just one direction at a time are shown.

In particular, it can be noted that the total RPE is showing local minimums even where the single leaf pattern has a peak, which is consistent with the results of the simulations.

In Figure 33 and Figure 34, the elevation sections of the RPE in the direction of the beam at azimuth of 0° in the cases of 0° and -3° electrical steering are shown.

The vertical axis reports the relative level (dB) at the measurement receiver, considering a maximum e.i.r.p. per beam of 50 dBm as in the simulations.

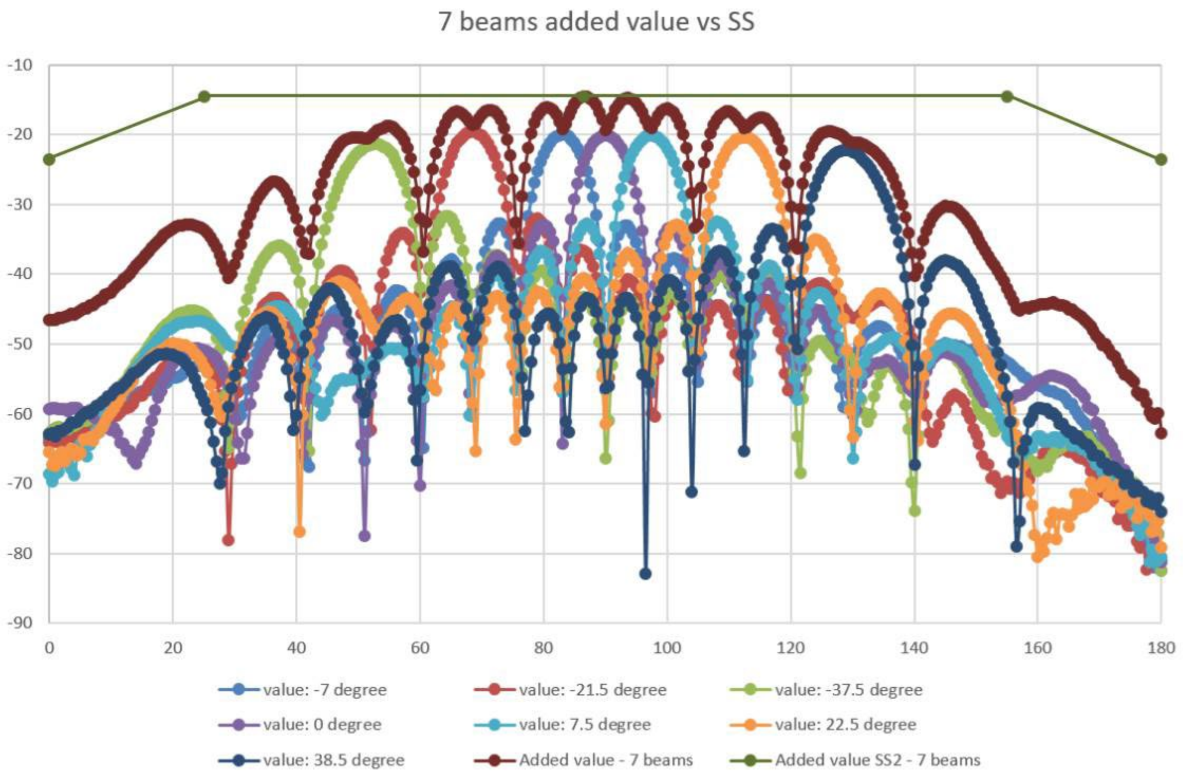


Figure 32: PMP RPE horizontal section versus ETSI PMP mask in azimuth

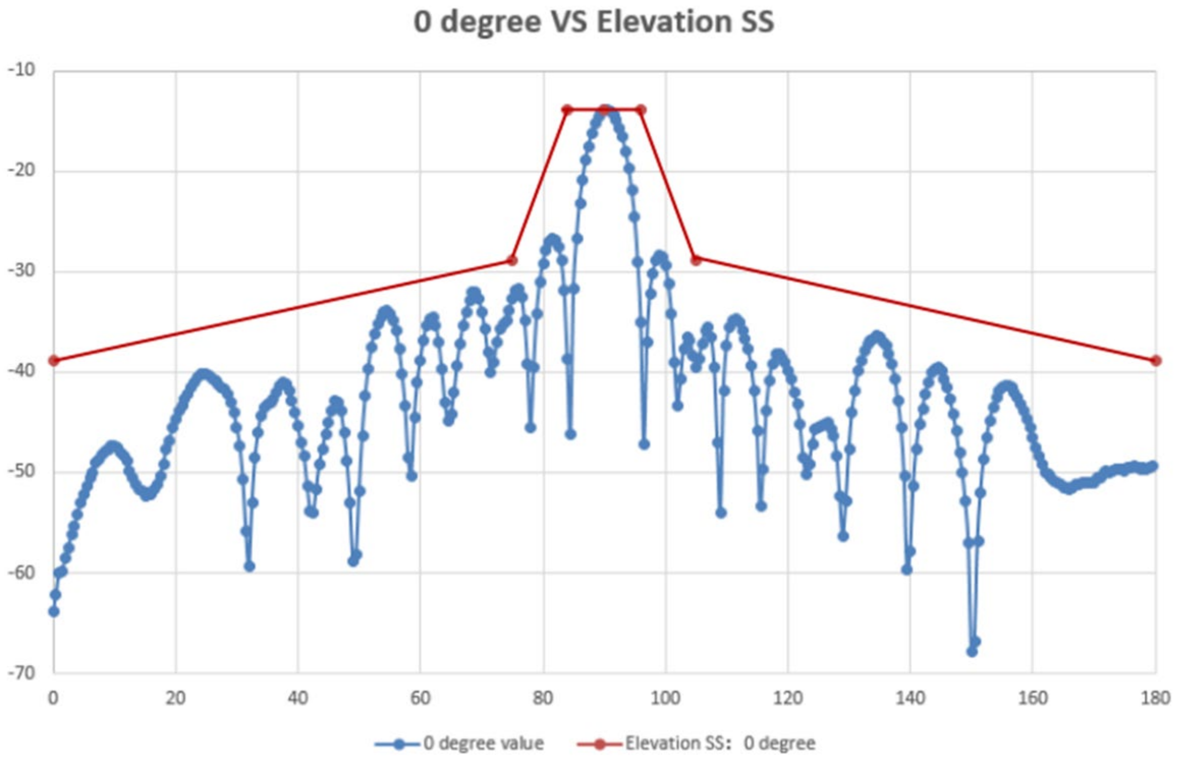


Figure 33: PMP RPE vertical section versus ETSI PMP mask in elevation with 0° steering

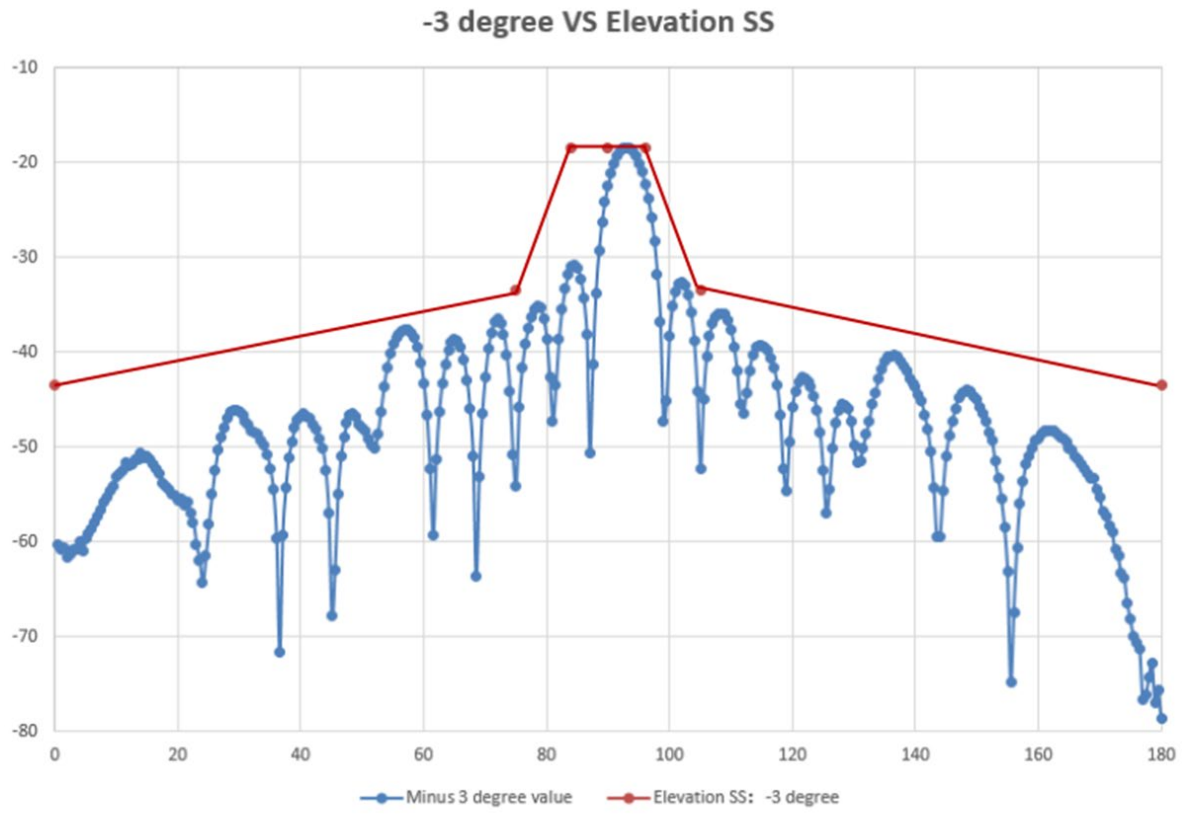


Figure 34: PMP RPE vertical section versus ETSI PMP mask in elevation with -3° steering

These preliminary measurements show two important features:

1. There is very good correspondence between simulations and measurements;
2. The measurements are compliant with the required ETSI masks for PMP systems both in azimuth and elevation.

## ANNEX 4: LIST OF REFERENCES

[1] Recommendation ITU-R M.2083-0: "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond"

[2] ETSI White Paper No. 25 Industry Specification Group on millimetre Wave Transmission(ISG mWT): “Microwave and Millimetre-wave for 5G Transport”, first edition, February 2018

[3] ECC Decision (05)01: " ECC Decision of 18 March 2005 on the use of the band 27.5-29.5 GHz by the Fixed Service and uncoordinated Earth stations of the Fixed-Satellite Service (Earth-to-space) ", latest amended March 2019

[4] ERC Recommendation T/R 13-02: "Recommendation T/R of 1993 on preferred channel arrangements for fixed service systems in the frequency range 22.0-29.5 GHz", latest amended on 29 May 2019

[5] ECC Recommendation (11)01: "ECC Recommendation of 2 February 2011 on guidelines for assignment of frequency blocks for Fixed Wireless Systems in the bands 24.5-26.5 GHz, 27.5-29.5 GHz and 31.8-33.4 GHz"

[6] Recommendation ITU-R P.837-7: "Characteristics of precipitation for propagation modelling"

[7] Recommendation ITU-R M.2101-0 (02/2017): "Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies"

[8] Recommendation ITU-R F.2086-0: "Deployment scenarios for point-to-point systems in the fixed service"

[9] ETSI EN 302 326-3: “Fixed Radio Systems; Multipoint Equipment and Antennas; Part 3: Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive for Multipoint Radio Antennas”

[10] ERC Recommendation 74-01: "ERC Recommendation of 1998 on unwanted Emissions in the Spurious Domain", latest updated 1 October 2021

[11] Mailloux, Robert J. Phased Array Antenna Handbook. Second edition, Artech House, 2005

[12] ETSI TS 138 141-2: “5G NR; Base Station (BS) conformance testing, Part 2: Radiated conformance testing”

[13] 3GPP TS 38.141-2: “NR Base Station (BS) conformance testing, Part 2: Radiated conformance testing NR; Base Station (BS) conformance testing Part 2: Radiated conformance testing”

[14] ECC Report 304: "Advanced technologies for fixed GSO FSS Earth Stations in the 27.5-29.5 GHz band", approved October 2019

[15] ECC Report 173: "Fixed Service in Europe Current use and future trends post 2016, approved March 2012 and amended 27 April 2018

[16] ECC Report 319: "Sharing and compatibility implications of high capacity P-P systems using a single channel instead of two adjacent channels with the same total bandwidth", approved October 2020

[17] Recommendation ITU-R P.530-16 : Propagation data and prediction methods required for the design of terrestrial line-of-sight systems (itu.int)