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TECHNICAL REPORT

**Use of innovative antenna systems within millimetre Wave Transmission and impacts on standards and regulations**

Reference

DTR/ATTMTMmWT-0027

Keywords

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# Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

# Modal verbs terminology

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# Executive summary

The present document deals with innovative technologies applicable to mmW transmission for what regards the antenna system. The traditional approach in MW transmission equipment is to have a TRX connected to an antenna by means of a connector which represents the reference point for requirement setting and for measurement of conformance. Antenna technology is evolving in different directions: on one side in the traditional way by achieving higher directivity to allow a greater system gain, on other sides by employing new architectures such as separated TX and RX antennas, active antennas and/or antennas integrated with the equipment.

Proper classification and terminology of antenna types is considered in clause 4.

Clauses 5 and 6 of the present document analyse high directivity detachable antennas and integrated non-detachable antennas in order to investigate the two most promising directions of innovation in antenna technology.

Dual band antennas to be used by systems employing Band and Carrier Aggregation (BCA) are considered in clause 7.

Clause 8 takes into account the possible new architectures when separated TX and RX antennas are used without the need for a duplex filter (FDD systems) or a switch (TDD systems); this opens the way to possible new duplex schemes such as flexible FDD (fFDD), with the possibility to flexibly define the distance in frequency between TX and RX, or even Full Duplex (FD). This new architecture is particularly interesting when going to high frequencies as in D band where, leveraging on the short wavelength, compact antenna systems can be implemented, possibly with multiple antennas in one equipment. The impact on radio planning and spectrum regulation is considered as well.

Whilst high directivity detachable antennas do not change the way system requirements are set and conformance measurements are done apart from the definition of ever stricter antenna mask classes, integrated non-detachable antenna systems raise the important issues of how to define system requirements and how to measure the conformance to them, since an antenna connector is not any more available. In this case a paradigm shift is needed from conducted to radiated requirements, with accordingly defined measurements. These aspects are taken into account respectively in clauses 9 and 10.

# Introduction

The present document deals with innovative technologies applicable to mmW transmission for what regards the antenna system. The different types of antennas that can be used in MW and mmW systems can be classified according to different features, such as:

- Detachable vs. non-detachable, where a non-detachable antenna is one fully integrated with the rest of the equipment.
- Passive vs active, where an active antenna is one containing active components able to modify amplitude and/or phase of the input signal.
- Time variant vs static, where a time variant antenna is one with radiated pattern changing in time during working conditions.

The traditional antenna used in MW radio links for Fixed Service is a passive detachable one, where system requirements are defined and verified at the antenna connector; the antenna is characterized by parameters like gain, bandwidth and loss and represented by its radiation pattern in space. Harmonised standards have been developed at ETSI for PtP [i.1] and PtMP [i.2] systems within this logical frame, where the antenna part is dealt with in related ETSI standards [i.3], [i.4].

Innovation in passive, detachable antenna has directed towards ever improving directivity according to progressively more stringent antenna masks as defined by ETSI standards [i.3], [i.4], going in time from class 1 to class 4 types for PtP systems and from DN1 to DN5 for PtMP systems and possibly over.

When going towards frequencies in the mmW range the increasingly shorter wavelength makes antenna integration into the equipment feasible and advantageous from both technical and cost sides. In particular when considering D band (130 - 174,8 GHz range) the possibility to design a compact radio unit with integrated antennas has been already demonstrated with some prototypes and several research activities are ongoing on the subject. One prototype with passive, non-detachable and distinct TX and RX antennas was deployed in Milan in November 2016 for propagation investigations in D band [i.5]. Another prototype with active, integrated antennas was developed within the Horizon 2020 framework as well [i.6].

A great push towards the development of innovative antenna systems is coming from the introduction into IMT-2020 of Active Antenna Systems (AAS), which employ antenna array structure with active elements within the antenna in order to control the amplitude and phase of the signals to the single elements of the array. In this way beamforming is possible and the antenna pattern can be adaptively modified in time in order to adapt to the changing propagation conditions and user distribution.

When considering a non-detachable antenna, whether passive or active, the problem of defining the system requirements and their measurement requires a paradigm shift, since it is necessary to pass from conducted to radiated requirements and measurements. This change requires the measurements to be done in a controlled environment such as an anechoic chamber so to avoid any unwanted influence from the surrounding environment. A good reference is the work done in 3GPP for IMT2020 systems and implemented in the related ETSI standards as well [i.14].

The present document investigates the use of innovative antenna systems within millimetre Wave transmission and impacts on standards and regulations. Clause 4 considers the classification and related terminology of antenna types. In clause 5 evolution along the traditional path of passive, detachable antenna is considered, whilst clause 6 analyses the integrated antenna evolution path, both sections dealing with technological aspects. Clause 7 takes into account the dual band antennas that are developed within the concept of BCA [i.9], [i.17], where an antenna able to effectively handle signals at two different bands is required. Clause 8 analyses the impacts on spectrum management and regulation of the innovative architectures allowed when using distinct TX and RX antennas, where concepts such as fFDD and full duplex become feasible. Finally clauses 9 and 10 take into consideration the impacts on requirement setting and conformance measurement.

# 1 Scope

The present document deals with innovative technologies applicable to mmW transmission for what regards the antenna system.

# 2 References

## 2.1 Normative references

Normative references are not applicable in the present document.

## 2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

The following referenced documents may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.


[i.1] ETSI EN 302 217-2: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 2: Digital systems operating in frequency bands from 1 GHz to 174,8 GHz; Harmonised Standard for access to radio spectrum".

[i.2] ETSI EN 302 326-2: "Fixed Radio Systems; Multipoint Equipment and Antennas; Part 2: Harmonised Standard for access to radio spectrum".

[i.3] ETSI EN 302 217-4: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4: Antennas".

[i.4] ETSI EN 302 326-3: "Fixed Radio Systems; Multipoint Equipment and Antennas; Part 3: Multipoint Antennas".

[i.5] Luini L., Roveda G., Zaffaroni M., Costa M., Riva C. (2018): "EM wave propagation experiment at E band and D band for 5G wireless systems: preliminary results". Proceeding of EuCAP 2018, 9-13 April 2018, pp. 1-5, London, UK.

[i.6] M. Frecassetti et al.: "SiGe:BiCMOS technology is enabling D-band link with Active Phased Antenna Array", 2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit).

[i.7] ECC Report 342: "Microwave Point-to-Multipoint technologies based on active antennas for 5G backhaul above 27.5 GHz".

[i.8] Recommendation ITU-R M.2101-0 (2017): "Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies".

[i.9] ECC Report 320: "Band and Carrier Aggregation in fixed point-to-point systems".

[i.10] ECC Recommendation (18)01: "Radio frequency channel/block arrangements for Fixed Service systems operating in the bands 130-134 GHz, 141-148.5 GHz, 151.5-164 GHz and 167-174,8 GHz".

[i.11] Roveda G., Costa M. (2018): "Flexible Use of D Band Spectrum for 5G Transport: a Research Field Trial as Input to Standardization". Proceeding of PIMRC 2018, 9-12 September 2018, Bologna, Italy.

[i.12] ETSI EN 301 126-1: "Fixed Radio Systems; Conformance testing; Part 1: Point-to-point equipment - Definitions, general requirements and test procedures".

[i.13] ETSI EN 301 126-3-1: "Fixed Radio Systems; Conformance testing; Part 3-1: Point-to-Point antennas; Definitions, general requirements and test procedures".

[i.14] ETSI TS 137 145-2: "Universal Mobile Telecommunications System (UMTS); LTE; 5G; Active Antenna System (AAS) Base Station (BS) conformance testing; Part 2: radiated conformance testing (3GPP TS 37.145-2)".

[i.15] ETSI EN 302 217-1: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 1: Overview, common characteristics and requirements not related to access to radio spectrum".

[i.16] ETSI EN 301 126-4: "Fixed Radio Systems; Conformance testing; Part 4: Definitions, general requirements and test procedures for radiated tests for point-to-point equipment and antenna".

[i.17] ETSI GR mWT 015: "Frequency Bands and Carrier Aggregation Systems; Band and Carrier Aggregation".

# 3 Definition of terms, symbols and abbreviations

## 3.1 Terms

Void.

## 3.2 Symbols

Void.

## 3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

| | |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| AAS | Active Antenna System |
| BCA | Band and Carrier Aggregation |
| EIRP | Equivalent Isotropic Radiated Power |
| FD | Full Duplex |
| FDD | Frequency Division Duplex |
| fFDD | flexile FDD |
| FS | Fixed Service |
| HPBW | Half Power Beam Width |
| IMT-2020 | International Mobile Telecommunications-2020 |
| mmW | millimetre Wave |
| MW | MicroWave |
| PoP | Point of Presence (of optical fibre) |
| PtMP | Point to MultiPoint |
| PtP | Point to Point |
| QoS | Quality of Service |
| RF | Radio Frequency |
| RPE | Radiation Pattern Envelope |
| RSL | Received Signal Level |
| RX | Receiver |
| TDD | Time Division Duplex |
| TRX | Transmitter and Receiver (Transceiver) |
| TX | Transmitter |

# 4 Antenna classification and definitions

Antennas can be classified according to several different criteria and parameters. They can be:

- Detachable or non-detachable according to the presence or not of an antenna connector available for conformance testing.
- Active or passive considering the presence or not of active components that may impact the antenna behaviour within the antenna itself (e.g. amplifiers, phase shifters, switches, etc.).
- Single-beam or multi-beam considering the presence in the radiated pattern of one or more main beams.
- Single frequency band or multi-band according to the emission spectrum being in one or more bands.
- With or without beam-forming capability according to the possibility to modify the radiated pattern.
- Static or time-variant according to the constant or variable radiated pattern in time during working conditions.

The different types of antennas can be a combination of this classification criteria; one example is the traditional Fixed Service MW parabolic antenna that is detachable, passive, single beam, single frequency, without beam-forming and static; another example is the AAS of a mobile system that is non-detachable, active, multi-beam, single frequency, with beamforming and time variant.

For what regards the present document the main important consideration is the availability of an antenna connector in the equipment, because this is the discriminant between the possibility to set the requirements and conformance testing in a "conductive" way and the necessity to develop them in a "radiated" way.

In the "conductive" way a measurement instrument can be connected directly to the antenna connector of the equipment instead of the antenna. This is the current situation for FS equipment in ETSI EN 302 217-1 [i.15], where the antenna connector is well defined as shown in Figure 1 at section C/C'.

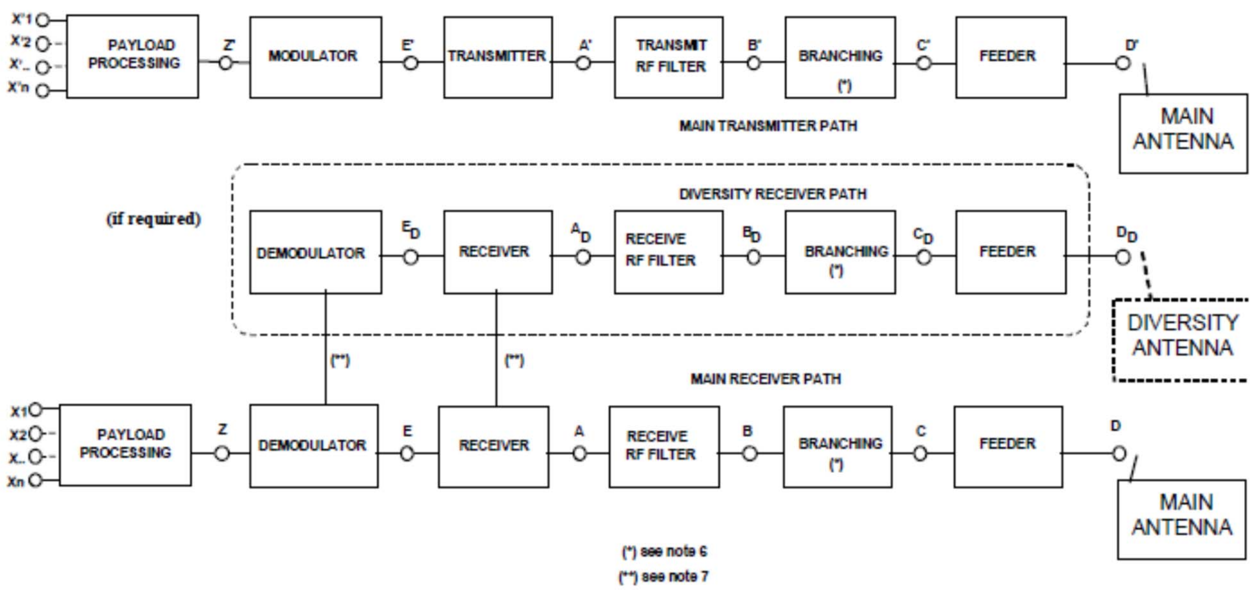


**Figure 1: ETSI system block diagram with antenna connector D**

In the "radiated" way the measurement is to be done on the integral equipment including its own antenna, with the instrument connected to its own antenna and both equipment and instrument placed into a controlled environment such as an anechoic chamber. This is a new situation for FS equipment to be properly studied, in particular when considering mmW frequencies where the sensitivity of measurement instruments is a critical issue.

It is worthwhile to note that in some cases even if an integrated antenna could be physically separated from the radio part, nevertheless when control signals are needed to the antenna part in order for it to work properly this case should be considered as non-detachable as well.

A comparison among different models is shown in next clause on the base of experimental data.

# 5 High directivity detachable antennas at mmW

## 5.1 ETSI antenna classes

### 5.1.1 Point to point systems

ETSI Harmonised Standards for Fixed Service ([i.3], [i.4]) classify the different types of antennas according to well defined masks in the space domain defining different antenna classes, according to the frequency range, the azimuth or elevation direction and the co-polar or cross-polar behaviour.

In the case of PtP systems (ETSI EN 302 217-4 [i.3]) and with respect to the Radiation Pattern Envelope (RPE) four classes (RPE classes 1 to 4) have been defined in the co-polar case and azimuth plane, summarized in Table 1.

**Table 1: Corner points of co-polar limits for actual RPE templates**

| RPE classes (see note 1) | Co-polar maximum limit templates for actual RPEs | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Range 1 GHz to 3 GHz (see note 2) | | Range 3 GHz to 30 GHz | | Range 30 GHz to 71 GHz (see note 3) | | Range 71 GHz to 174,8 GHz | |
| | Azimuth angle (°) | Maximum gain (dBi) | Azimuth angle (°) | Maximum gain (dBi) | Azimuth angle (°) | Maximum gain (dBi) | Azimuth angle (°) | Maximum gain (dBi) |
| 2 | 40 | 5 | 20 | 12 | 20 | 12 | 20 | 7 |
| | 90 | 5 | 80 | 2 | 70 | 0 | 40 | 2 |
| | 120 | -10 | 105 | -18 | 90 | -17 | 70 | -2 |
| | 180 | -10 | 180 | -18 | 180 | -17 | 88,75 | -7 |
| | | | | | | | 100 | -7 |
| | | | | | | | 100 | -10 |
| | | | | | | | 180 | -10 |
| 3 | 30 | 3 | 20 | 8 | 20 | 1 | 20 | 1 |
| | 80 | 2 | 65 | -2 | 50 | -1 | 50 | -1 |
| | 110 | -15 | 100 | -22 | 70 | -4 | 70 | -4 |
| | 180 | -15 | 180 | -22 | 90 | -17 | 90 | -17 |
| | | | | | 180 | -17 | 180 | -17 |
| 4 | 25 | 0 | 20 | -4 | 20 | -4 | 20 | -4 |
| | 75 | -5 | 105 | -30 | 90 | -21 | 90 | -21 |
| | 105 | -20 | 180 | -30 | 180 | -21 | 180 | -21 |
| | 180 | -20 | | | | | | |

NOTE 1: Class 1 antennas are defined as those which actual RPE exceeds class 2 template limit.
NOTE 2: No specific class 4 antenna RPE is defined for this frequency range; the corresponding limit template in table 1 is set for possible future use.
NOTE 3: No specific class 4 antenna RPE is defined for the frequency range 47 GHz to 71 GHz; the corresponding limit template in table 1 is set for possible future use.

The antenna classes define the directional properties of the antenna, the higher the class the higher the directivity of the antenna and the lower the interference impact to be considered in network planning.

### 5.1.2 Point to Multipoint systems

Similar classes have been defined for PtMP systems (ETSI EN 302 326-3 [i.4]) for the different types of antennas used (directional, sectorial and omnidirectional), in line with the principle that antennas with more demanding maximum combined co-polar and cross-polar RPEs have higher class numbers:

- Directional antennas have 5 classes, from DN1 to DN5.
- Single-beam sectoral antennas have 4 classes, from SS1 to SS4.
- Multi-beam sectoral antennas have 2 classes, MS1 and MS2.
- Omnidirectional antennas are not differentiated in classes.

## 5.2 New high directivity antennas

### 5.2.1 High space-selectivity (ETSI class) antenna systems

Technology evolution in detachable antennas and ever-increasing requirements in terms of interference handling will bring new antenna systems with possibly higher classes than current ETSI most demanding ones.

As operational frequencies increase there is a requirement for interference mitigation using higher class RPE's, such as class 4, to allow for better spectrum utilization and improving link density. To illustrate antenna performance relative to a class 4 mask, an example of measurement is shown for class 4 at 42 GHz band (Figure 2).

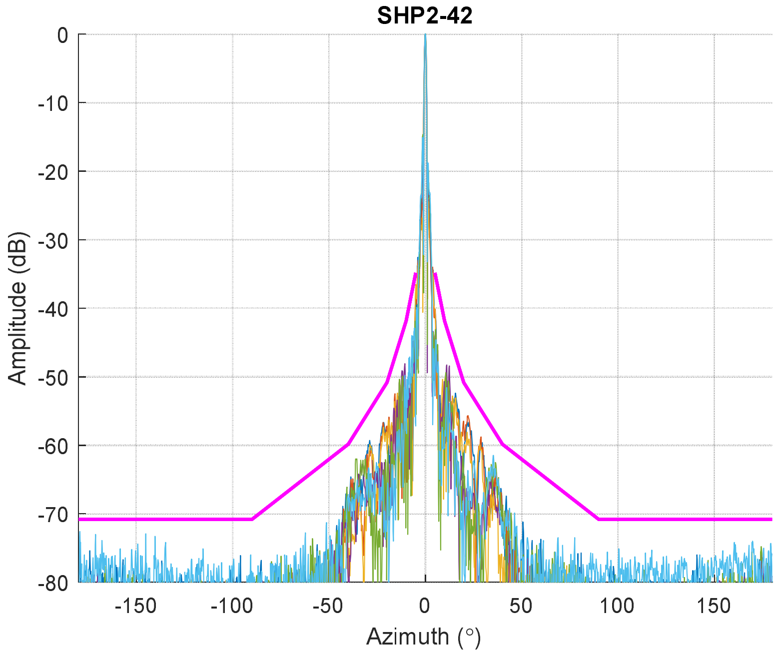


**Figure 2: Measured Co-Pol radiation pattern for 2ft antenna @ 42 GHz - ETSI Class 4 RPE**

At this point in time class 3 at E-Band is generally considered as the 'standard' (an example of measurement is shown in Figure 3), but going forward there is a potential requirement for class 4 at E-Band (an example of simulation is shown in Figure 4), which can be attributed to expanding growth/densification of backhaul systems at E-Band. Comparing Figure 3 and Figure 4 it can be clearly seen the significant improvement in side-lobe performance that a class 4 antenna has over a class 3.

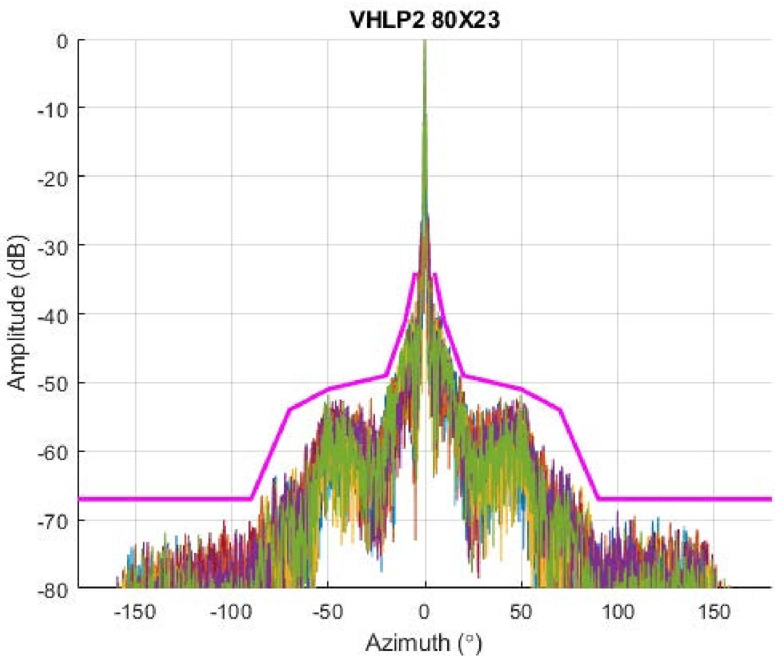


**Figure 3: Measured Co-Pol radiation pattern 2ft antenna @ E-Band - ETSI Class 3 RPE**

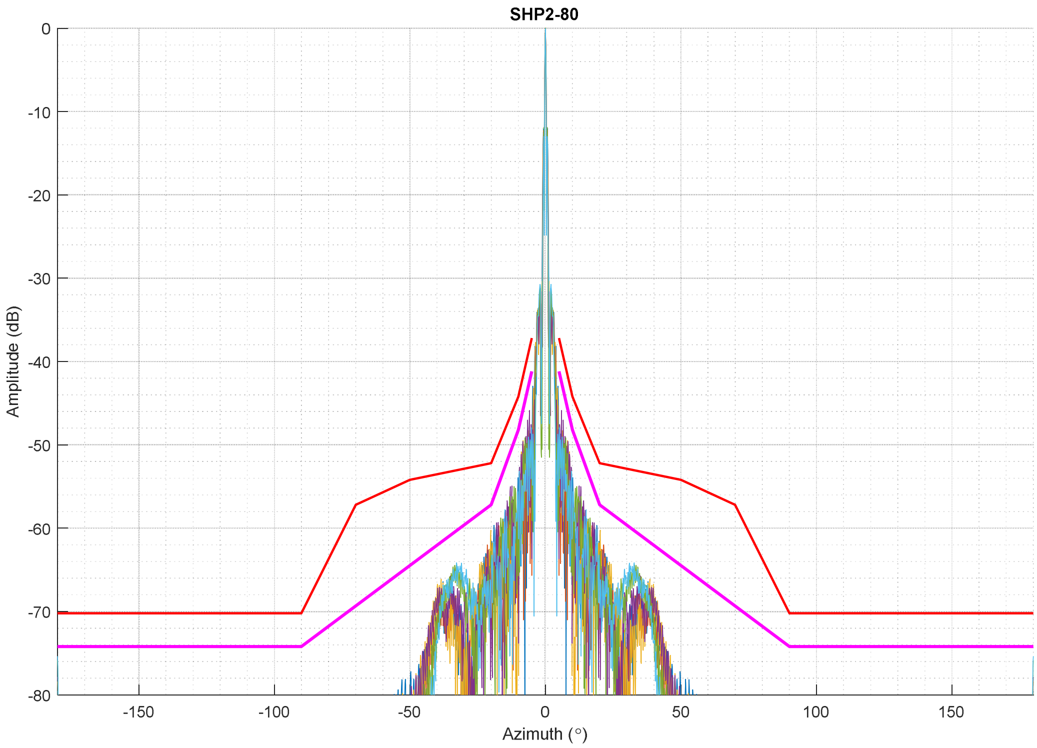


**Figure 4: Simulated Co-Pol radiation pattern 2ft antenna @ E-Band - ETSI Class 3 (red) & 4 (magenta) RPEs**

### 5.2.2 Electro-mechanical alignment-tracking antenna systems

As long as the directivity of the antenna is increased the issue of maintaining the alignment of the link with pole swaying and/or bending due to thermal and/or wind reasons becomes more relevant.

The entity of antenna swaying and bending depends on several factors:

- Atmospheric situation (temperature variation, wind speed).
- Type of pole (mono-pole, roof-pole, mast, tower).
- Material and height of pole.

The reduction in Received Signal Level (RSL) becomes significant when the pole swaying angle becomes comparable to the 3 dB beamwidth (HPBW) as shown in Figure 5; as a consequence the relevance of the issue grows with antenna gain and with frequency.

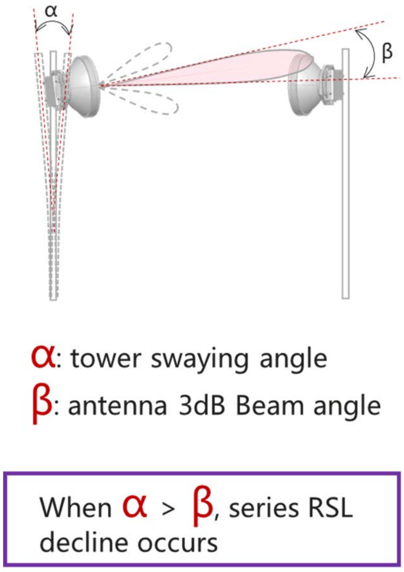


**Figure 5: Sway angle and HPBW**

In Table 2 some typical values at 23 GHz and E band are shown.

**Table 2: Typical values of HPBW**

| Antenna | 3 dB Beam |
|---|---|
| 30 cm 23 GHz | 3° (±1,5°) |
| 60 cm 23 GHz | 1,7° (±0,85°) |
| 30 cm 80 GHz | 0,9° (±0,45°) |
| 60 cm 80 GHz | 0,5° (±0,25°) |

In Figure 6 typical values of sway angles are shown.

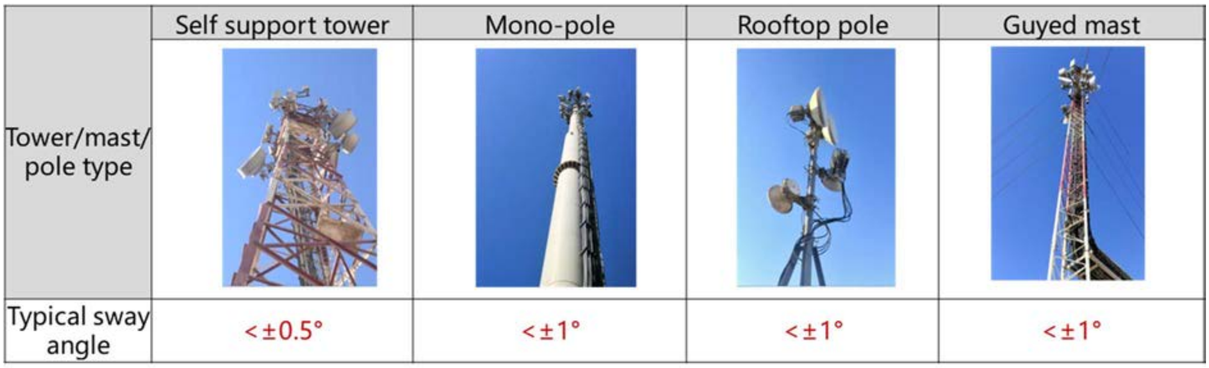


**Figure 6: Typical sway angle for different pole types**

In case of deployment over a lamp pole the sway angle can be typically > 2°.

From the typical values shown in Table 2 and Figure 6 it is evident that the issue of maintaining link alignment becomes relevant at high mmW, starting from E band and over.

Different systems which are able to control adaptively the link alignment can be considered:

- In traditional parabolic antennas an electro-mechanical adaptation of the orientation of the antenna can be implemented.
- In phased array antennas link alignment can be maintained by leveraging on beam-steering (see clause 6.2.5).

The control mechanism has to be fast enough to be able to compensate for both swaying due to wind and bending due to temperature variation.

# 6 Integrated non-detachable antennas at mmW

## 6.1 Passive integrated antennas

A passive integrated antenna is a non-detachable antenna without active components in it.

An example of this kind of antenna is the one used by the D band prototype operating at Politecnico of Milan since November 2016 [i.5], which is an array antenna whose elements are fed by a passive distribution network in order to get a fixed and directive RPE. This antenna is connected directly at the RF front end and is not detachable from the rest of the system once the equipment is assembled.

In this type of antennas an equivalent antenna port can be defined with an equivalent gain even if a physical port is not accessible; in this case by measuring the EIRP and knowing the declared antenna gain a TX power at the virtual antenna port can be calculated.

## 6.2 Active integrated antennas

### 6.2.1 General concept

An active integrated antenna is a non-detachable antenna with active components within the antenna itself, with the possibility to control the antenna pattern (beamforming) either only at initial configuration (fixed pattern) or during operation (time-varying pattern).

A very well-known example of active integrated antenna is given by phased array systems in which the antenna is constituted by a proper spatial distribution of radiating elements, the input signal to each one being controlled in amplitude and phase by means of active components, namely amplifiers and phase shifters.

By controlling the amplitude and phase of the input signal to the antenna elements the generated radiation pattern can be controlled and defined in what is known as beamforming; from the technological point of view beamforming can be implemented in the analogue domain, in the digital domain or with a hybrid implementation.

In any case the produced radiation pattern is given by the product of two main factors:

- The **element factor**, which is the radiating pattern of a single element in the array and depends on the type of radiating element chosen for the specific implementation; in the most common implementations the element factor is the same for all antenna elements.
- The **array factor**, which is fully defined by the geometry of the array and the frequency of operation, which in the common case of uniform distribution is just function of the number of elements and the element spacing as related to the wavelength.

The boresight of the antenna is defined as the direction orthogonal to the antenna plane.

In order to understand the basics of the behaviour of phased array antennas the following simple assumptions can be initially taken:

- The elements are equally spaced.

- The spacing between elements is half-wavelength.
- The amplitude of all elements is the same.
- The phase shift between elements is equal.

In this case the radiation pattern would be in the boresight direction, with small sidelobes decreasing according to a sin(x)/x envelope. The higher the number of elements, the higher the number of sidelobes but the faster their attenuation when going away from boresight and the narrower the beam-width.

The radiation pattern produced in this simplified case can be seen in Figure 7.

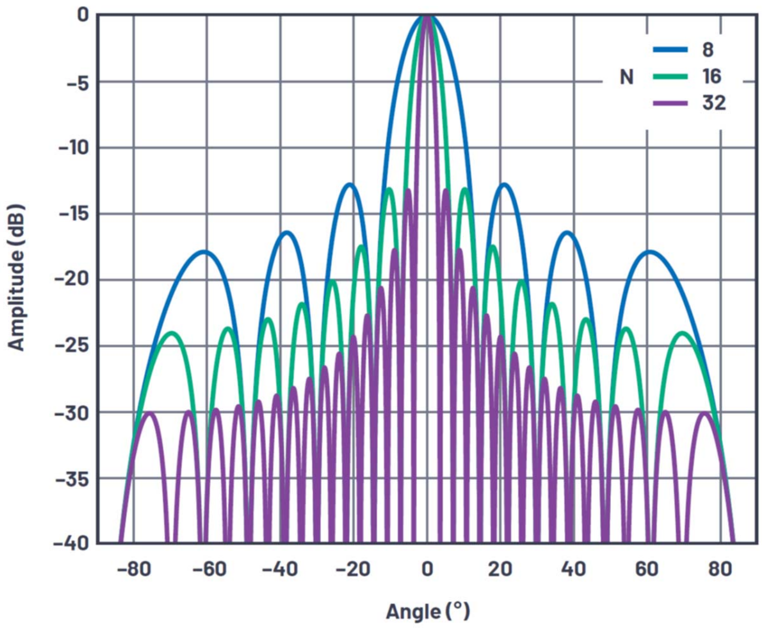


**Figure 7: Normalized radiation pattern in simplified case with number of elements of 8, 16 and 32**

In order to move the peak of RPE away from the boresight it is sufficient to modify the phases of the single elements, producing what is known as **beam-steering**.

When shifting the beam away from the boresight the radiation pattern changes according to both the single element pattern and the number of elements, but in general the wider the steering angle the lower the peak of the main beam and the wider its beam-width.

The normalized radiation pattern with three steering angles is shown in Figure 8, where the effect of the element pattern, reducing the main beam amplitude when shifting away from boresight, is not considered.

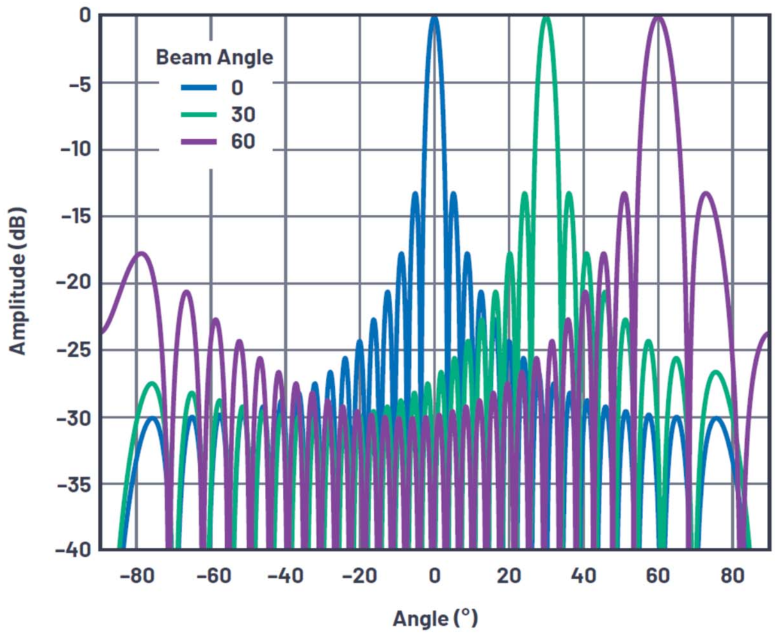


**Figure 8: Normalized radiation pattern in simplified case with beam-steering (case of 32 elements)**

Once understood the basic impact of the single parameters to the phased antenna radiation pattern, the simplified assumptions taken at the beginning of the clause can be removed, adding degrees of freedom and complexity to the behaviour of the antenna system.

For example if changing amplitude and phase of the signal given to the single elements, the radiation pattern can be not only beam-steered but more in general beam-formed.

Also the element spacing can be in general different from half wavelength, taking into account the feasibility limitations of the antenna array itself when considering mmW frequencies.

It is a well-known property of phased arrays that when using an element distancing larger than half wavelength, constructive interference will happen in directions other from the boresight (spatial aliasing effect), becoming even more significant when steering the beam: these peaks are known as **grating lobes** and are to be kept under control since they represent radiated energy in unwanted directions.

In the case of uniform element spacing:

- for $d > \lambda$ grating lobes can be seen in the visible zone ($-90° < \theta < +90°$) even without any steering;
- for $\lambda/2 < d < \lambda$ grating lobes enter the visible zone only when steering.

Given a maximum steering angle $\theta_{max}$ that the system has to fulfil, there is a maximum element spacing $d_{max}$ that can be used to avoid the appearance of grating lobes in the steering zone:

$$d_{max} = \lambda/(1+\sin\theta_{max})$$

So there is a trade-off between the maximum steering angle and the element spacing that can be used in the design of the phased array.

In even more complex antenna systems the distribution of the elements could in general be non-uniform and the element pattern itself could be different for different elements.

## 6.2.2 Static active integrated antennas

An active integrated antenna is static in case the controls on active elements of the antenna are defined at the configuration of the system and not changed any more during operation.

An example of use of this kind of active antenna is given by a PtMP system with star topology in which the beamforming capability is used at installation in order to direct the peaks of its RPE from a central point to the leaf sites. With regard to a traditional PtMP system, where a passive sector antenna is used at the node in order to cover a certain area where terminals are located, this new concept of PtMP employs an optimized RPE in order to maximize SINR leveraging on beamforming and on interference cancellation technologies. The structure of such a PtMP system is shown in Figure 9.

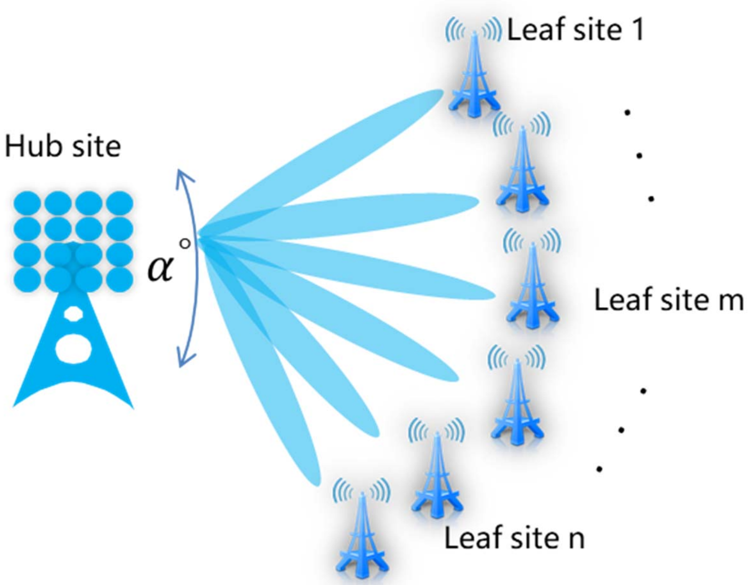


**Figure 9: General structure of a PtMP system based on active integrated antenna**

Considering as an example a sector 90° wide with 8 terminals to be connected to a central hub, the resulting RPE from the hub is shown in Figure 10.

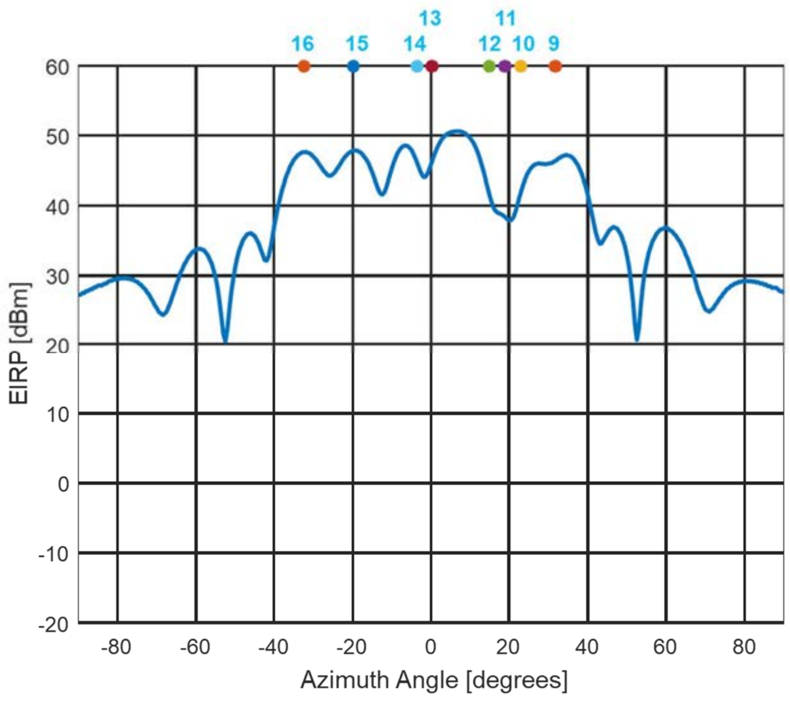


**Figure 10: Example of overall RPE from a hub to a 90° sector with 8 terminals**

The main use case for this PtMP system is backhauling of mobile networks, where the trend of the optical fibre to reach more and more in depth the extent of the mobile network generates the need for connecting the PoP of the fibre to the locations of the base stations surrounding the PoP, as shown in Figure 11.

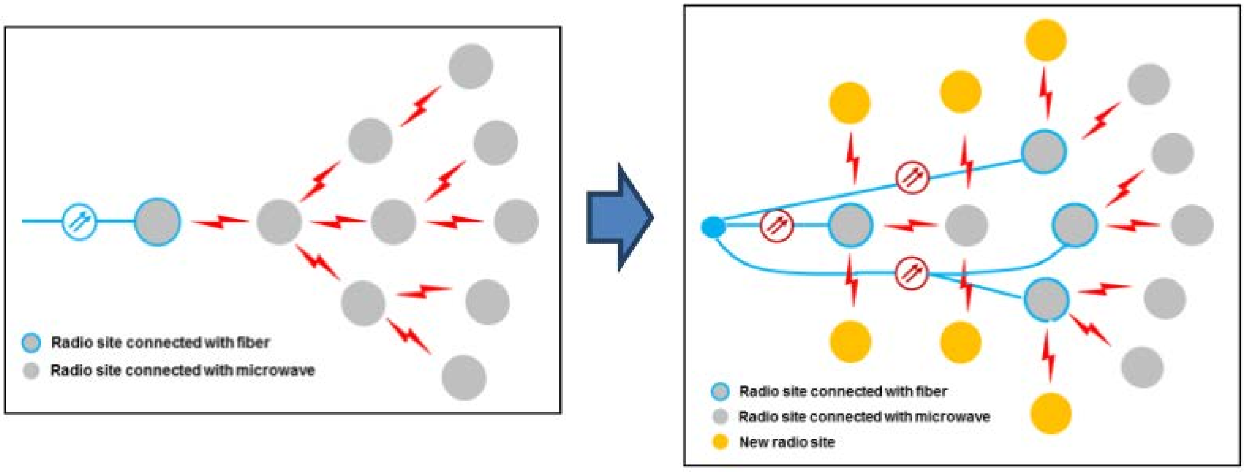


**Figure 11: Topology evolution of backhaul network**

The description of this innovative PtMP system can be found in ECC Report 342 [i.7].

## 6.2.3 Time varying active integrated antennas

An active integrated antenna is time varying in case the controls on active elements of the antenna are adaptively changing during operation. In case only the phases are controlled there is beam-steering systems where the direction of the main beam can be modified; in case both amplitudes and phases are controlled there is beam-forming systems where the antenna pattern can be modified.

The AAS used in IMT-2020 is a good example of a time-varying active integrated antenna system. In an AAS the antenna pattern is adaptively changing as a consequence of two main external factors:

- The propagation environment, in which reflections, diffractions and transmissions are in general depending on time as long as the involved obstructing body is moving.
- The user equipment distribution in space, which in general is changing in time since the terminals are moving.

When dealing with Fixed Service the possibility of having one end of the link in movement is of course excluded. Nevertheless the possibility of antenna systems adaptive with the changes in propagation environment can be considered within Fixed Service, considering for example radio networks with mesh topology and real time re-configurability.

The model used to describe analytically the antenna pattern of AAS is contained in Recommendation ITU-R M.2101-0 [i.8]. The spherical coordinates of reference are described in Figure 12.

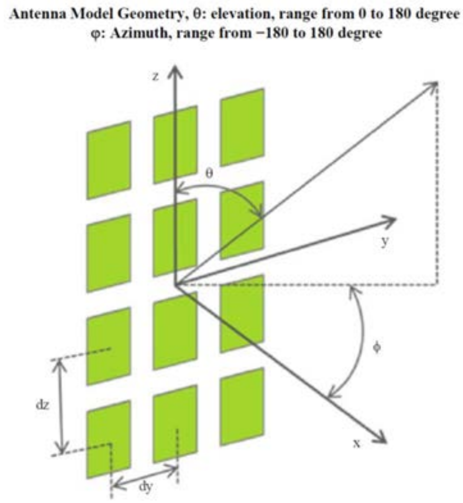


**Figure 12: Spherical coordinates for AAS**

The M.2101 model foresees some input parameters that are defined by the specific design for both the single element pattern and the composite antenna pattern, as reported in Table 3 and Table 4.

**Table 3: Element pattern for antenna array model**

| | |
|---|---|
| Horizontal Radiation Pattern | $A_{E,H}(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right] dB$ |
| Horizontal 3dB bandwidth of single element / deg ($\varphi_{3dB}$) | Input parameter |
| Front-to-back ratio: $A_m$ and $SLA_v$ | Input parameter |
| Vertical Radiation Pattern | $A_{E,V}(\theta) = -\min\left[12\left(\frac{\theta-90}{\theta_{3dB}}\right)^2, SLA_v\right]$ dB |
| Vertical 3dB bandwidth of single element / deg ($\theta_{3dB}$) | Input parameter |
| Single element pattern | $A_E(\varphi,\theta) = G_{E,\max} - \min\{-\lfloor A_{E,H}(\varphi) + A_{E,v}(\theta)\rfloor, A_m\}$ |
| Element gain (dBi), $G_{E,\max}$ | Input parameter |

**Table 4: Composite antenna pattern for beamforming**

| Configuration | Multiple columns ($N_V \times N_H$ elements) |
|---|---|
| Composite array radiation pattern in dB $A_A(\theta,\varphi)$ | For beam $i$: $A_{A,Beami}(\theta,\varphi) = A_E(\theta,\varphi) + 10\log_{10}\left(\left\lvert\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{i,n,m}\cdot v_{n,m}\right\rvert^2\right)$ <br> the super position vector is given by: <br> $v_{n,m} = \exp\left(\sqrt{-1}\cdot 2\pi\left((n-1)\cdot\frac{d_V}{\lambda}\cdot\cos(\theta) + (m-1)\cdot\frac{d_H}{\lambda}\cdot\sin(\theta)\cdot\sin(\varphi)\right)\right)$, <br> $n = 1,2,\ldots N_V; m = 1,2,\ldots N_H$; <br> the weighting is given by: <br> $w_{i,n,m} = \frac{1}{\sqrt{N_H N_V}}\exp\left(\sqrt{-1}\cdot 2\pi\left((n-1)\cdot\frac{d_V}{\lambda}\cdot\sin(\theta_{i,etilt}) - (m-1)\cdot\frac{d_H}{\lambda}\cdot\cos(\theta_{i,etilt})\cdot\sin(\varphi_{i,escan})\right)\right)$ $\sqrt{}$ |
| Antenna array configuration (Row × Column) | Input parameter |
| Horizontal radiating element spacing $d/\lambda$ | Input parameter |
| Vertical radiating element spacing $d/\lambda$ | Input parameter |
| Down-tilt angle (degrees) | Input parameter |

Apart from the details that can be found in the referenced Recommendation, it can be noted that the main design parameters required to describe the AAS pattern are the following:

- 3 dB bandwidth of single element (H and V).
- Front to back ratio of single element (H and V).
- Single element gain.
- Number of elements (H and V).
- Element spacing (H and V).
- Mechanical down-tilt.

### 6.2.4 Consideration on the geometrical shape of the antenna

The traditional antenna of a microwave PtP radio is of circular section and consequently its RPE has circular symmetry. When dealing with innovative types of antennas the section may have in general a different shape, for example rectangular or square in the case of phased array antennas; in these cases, the RPE has not circular symmetry and the orientation of the antenna with respect to the reference coordinates is to be duly considered.

### 6.2.5 Electrical alignment-tracking antenna systems

As long as the directivity of the antenna is increased the issue of maintaining the alignment of the link with pole swaying and/or bending due to thermal and/or wind reasons becomes more relevant (see clause 5.2.2).

When considering time varying active integrated antennas the alignment can be maintained leveraging on the beam-steering feature, implementing a loop able to keep the beam alignment over the link.

# 7 Dual band antennas for BCA

## 7.1 BCA concept

Band and Carrier Aggregation (BCA) is a concept enabling an efficient use of the spectrum through a smart aggregation, over a single physical link, of multiple frequency channels (in the same or different frequency bands) [i.9], [i.17].

A logical scheme of the BCA, shown in Figure 13, includes a carrier aggregation engine and different physical radio channels. Most of the BCA benefits can be obtained thanks to the engine design which takes into account both the required traffic QoS and the conditions of the radio channels.

Radio channels (same or different frequency band) can be different in terms of:

- Channel size.
- Capacity and latency (according to the adopted radio profile).
- Availability - due to different frequency band and different results of the engineered link (solution performance linked to antenna size, system gain, etc.).
- Fixed or adaptive modulation scheme.
- License scheme - subjected to interference-free operation or not.

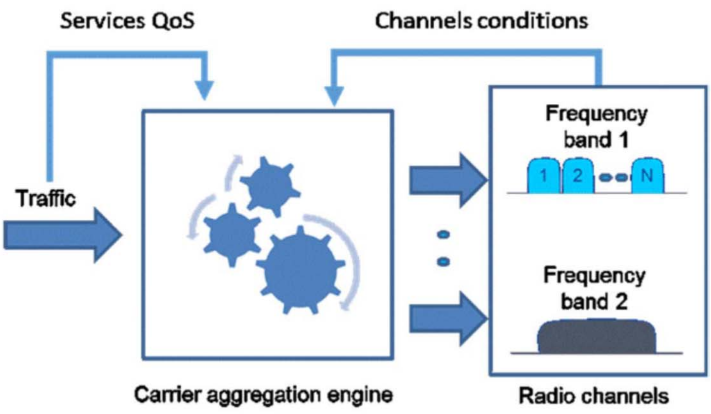


**Figure 13: BCA concept**

One of the most advantageous BCA configurations employs one link at traditional MW frequencies (e.g. 23 GHz) and one link at mmW (e.g. E band), where the high band is able to provide wide bandwidth (and consequently high throughput) for the majority of time whilst the low band provides the minimum committed capacity even in bad propagation conditions (e.g. with rain) assuring the required availability.

## 7.2 Dual band antenna

In order to get the higher advantage from a BCA solution, the availability of a dual band antenna able to work properly at both bands is essential. The main advantages with such technologies are:

- Lower cost of ownership (equipment count, tower footprint).
- Easier alignment during installation.
- Lower visual impact.

In particular the dual band antenna has to fulfil the following requirements at both bands:

- Same gain as the single antennas, in order to maintain link budget.
- Same performances as the single antennas in terms of radiation pattern, in order to preserve a safe interference situation.

Achieving these targets is a technological challenge because of the optimization required at different frequencies on the same unit. In the case of parabolic antenna for example multisource feed technology is suitable, where some aperture blockage effect will limit performances in particular at the higher band, as shown in Figure 14.

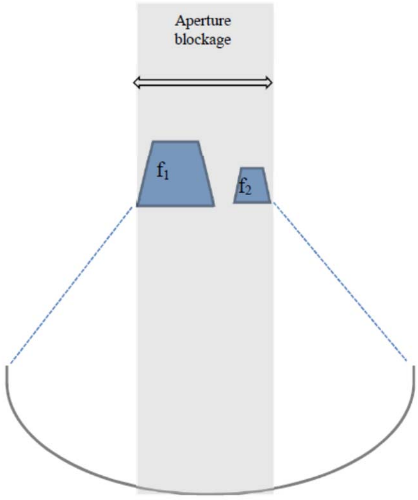


**Figure 14: Feed blockage effect**

The aperture blockage has impacts not only on antenna gain but also on side-lobes, the higher the distance between the two frequencies the higher the impact. Moreover other technological issues with dual band antennas are:

- Isolation between the bands to limit cross-talk interference.
- Antenna radome material electrically transparent to both bands.

Dual band antennas for BCA are available on the market on several band combinations; one example is a 38 GHz/E band antenna, where ETSI class 3 performance is achieved for both antennas with better than 25 dB isolation between the two bands and 2 dB lower gain than with single antenna.

# 8 New architectures with separated TX and RX antennas

## 8.1 Architecture

In order to separate TX and RX directions in traditional radio links the two traditional approaches adopted are separation in frequency (FDD) or in time (TDD).

The largely dominant solution in traditional MW links is FDD, implemented by means of duplexer filters which allows the use of one single antenna by providing two sufficiently isolated paths for TX and RX. The duplex separation in frequency is fixed per each frequency band and defined by proper regulation both at European (CEPT) and international (ITU-R) level.

Systems employing TDD substitute the duplexer with a switch allowing the proper alternation between TX and RX time slots, with isolation between TX and RX paths as the main figure of merit.

When considering mmW frequencies the dimensions of the antenna can be progressively reduced and the possibility to use two separated antennas for TX and RX within a reasonable equipment size begins to be feasible.

In particular when considering D band (130 - 174,8 GHz) antennas with dimensions in the order of 5 - 10 cm can be implemented as demonstrated in the prototype developed and deployed in November 2016 at Politecnico of Milan [i.5]. In this case two passive phased array antennas with length of about 4 cm by 4 cm have been used in the same equipment, with measured isolation between TX and RX paths shown in Figure 15.

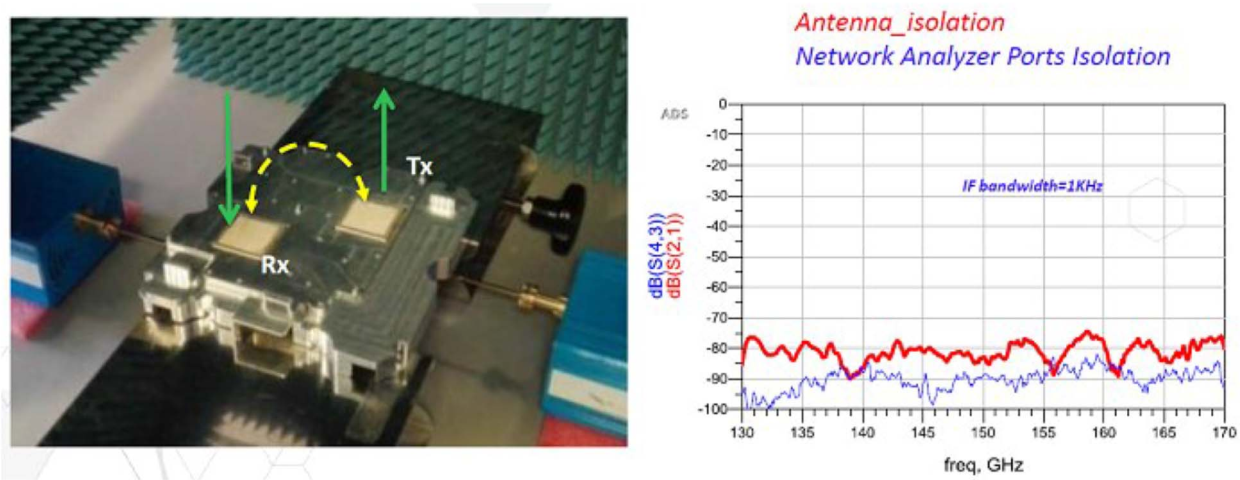


**Figure 15: Antenna isolation with separated TX and RX antennas at D band**

The measured isolation is well over 70 dB along the whole bandwidth of interest.

This kind of architecture provides two major advantages:

- The duplexer filter is not any more necessary.
- The duplex separation in frequency can be flexibly defined.

## 8.2 DREAM project

In the framework of the Horizon 2020, DREAM project [i.6] aims to demonstrate the feasibility of transceiver operating in D-band (130 - 174,8 GHz) with an active phased antenna array for beam steering functionality.

The DREAM project is based on a power efficient silicon based BiCMOS transceiver analogue front end for enabling a cost-efficient mass-production transceiver with a beam steering integrated antenna array using an intelligent low-cost packaging technology.

DREAM transceiver demonstrator has a 4x4 TX antenna array and 4x4 RX antenna array as shown in Figure 16, adopting for separating the transmitted and the received signal two different antennas instead of a more traditional diplexer filter in case of FDD or a switch in case of TDD approach (see clause 8.1).

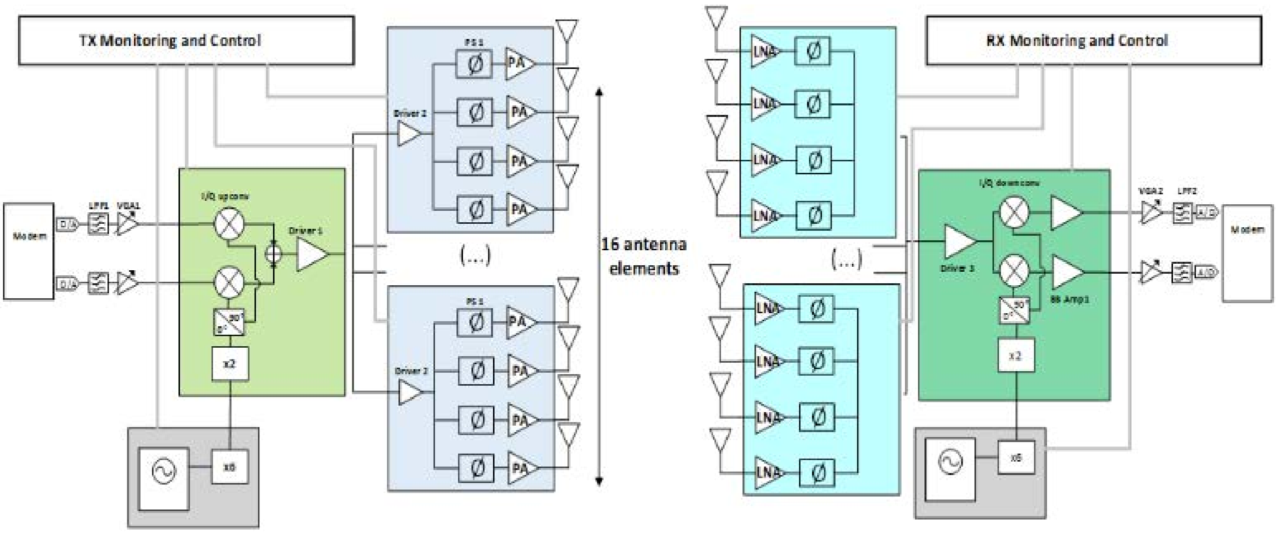


**Figure 16: Transceiver architecture with 4x4 TX antenna array and 4x4 RX antenna array**

The architecture is a simple and straightforward direct conversion (Zero IF) both for the TX and the RX side. This architecture can support either FDD or TDD, as duplex method. In addition to that, the demonstrator is ready to work in Full Duplex mode as well. Concerning the antenna implementation, each antenna element, RX or TX, has its own RF chain that includes amplification and phase shifter, implementing a full performance phase array for beam steering.

Preliminary results from the demonstrator test bench are very encouraging. Figure 17 shows the demonstrator set-up, on the left, and the very preliminary result of beam steering measurements on the right, taken from the receiver antenna. Substantially a ±40° steering angle has been obtained and considering that the antenna array elements coefficients have not yet been tuned, the antenna response appears very promising.

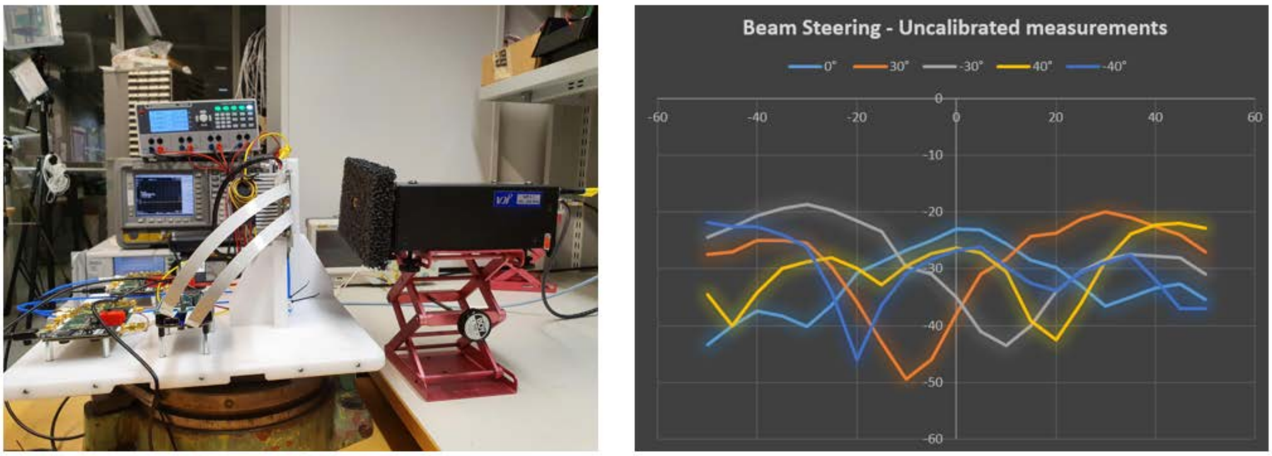


**Figure 17: DREAM demonstrator test bench and preliminary antenna steering results**

## 8.3 Flexible FDD (fFDD)

A system architecture that employs two separated antennas for TX and RX paths allows avoiding the use of a duplex filter with a fixed separation in frequency, provided that sufficient isolation is achieved between the two paths.

On this base a flexible scheme for spectrum management named flexible FDD (fFDD) is feasible and has been proposed in ECC Recommendation (18)01 [i.10] with regard to D band. According to the Recommendation the channel raster is made by N × 250 MHz channels, grouped in 4 sub-bands, as described in Figure 18 and Table 5.


**Figure 18: D band spectrum and channel raster (ECC Recommendation (18)01 [i.10])**

**Table 5: D band channelization (ECC Recommendation (18)01 [i.10])**

| | D band channels | Sub-band width |
|---|---|---|
| **Sub-band a** | Fn = 130 + N*0,250 GHz<br>N= [1 .. 15] | 15x250 MHz |
| **Sub-band b** | Fn = 141 + N*0,250 GHz<br>N= [1 .. 29] | 29x250 MHz |
| **Sub-band c** | Fn = 151.5 + N*0,250 GHz<br>N= [1 .. 49] | 49x250 MHz |
| **Sub-band d** | Fn = 167 + N*0,250 GHz<br>N= [1 .. 30] | 30x250 MHz |

The concept is that both channel width and duplex spacing can be freely defined under the conditions of respecting the central frequencies of the raster and of being multiples of 250 MHz.

The aggregation of N × 250 MHz basic channels is a block; channels inside the blocks can be associated in various ways:

- symmetric or asymmetric go-return configurations (whether go channel width is equal to its own return channel width or not);
- consecutive or alternate go-return configurations (whether all go channels are consecutive and followed by all return channels or each go channel is followed by its own return channel).

Some possibilities are described in the following examples and depicted in Figure 19.

Example 1 describes 4 identical go channels, followed by their respective 4 identical return channels.

Example 2 foresees 3 go channels of different widths, followed by their 3 return channels of the same respective width.

Example 3 describes 4 identical go channels, each one followed by its respective identical return channel.

Example 4 foresees 3 go channels of different widths, each one followed by its return channel of the same respective width.

Example 5 describes 3 go channels of different widths, followed by their 3 return channels of different respective width.

Example 6 foresees 3 go channels of different widths, each one immediately followed by its return channel of different respective width.

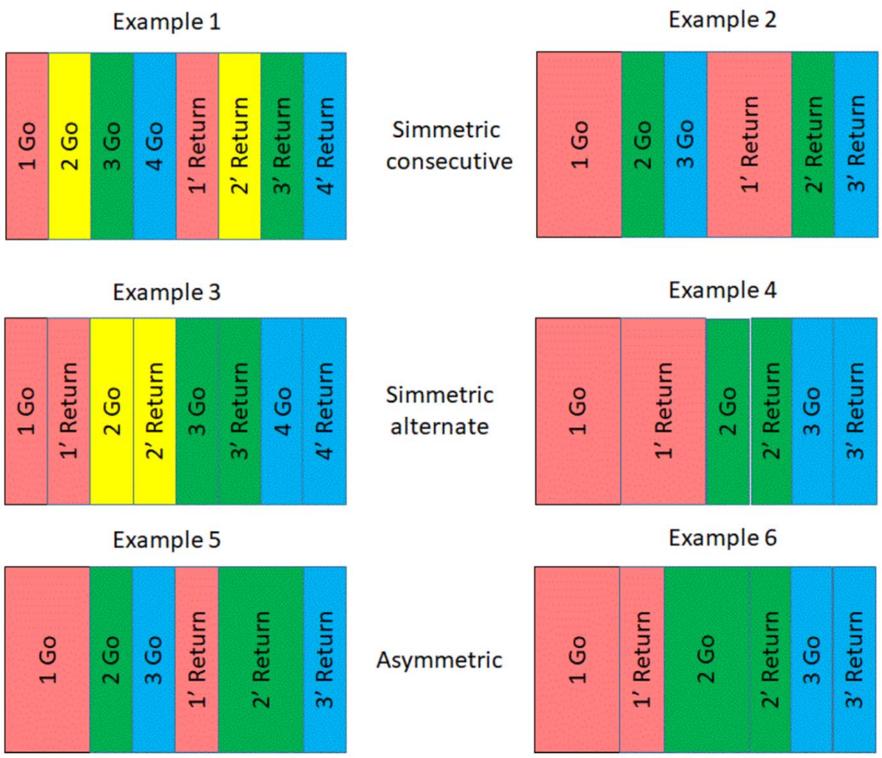


**Figure 19: Flexible FDD examples**

Even traditional paired duplexing between two blocks can be achieved, with both symmetric (Figure 20) and asymmetric (Figure 21) go-return channel size, taking into account that in this case a duplex step longer than 15 GHz is required by ECC Recommendation (18)01 [i.10].

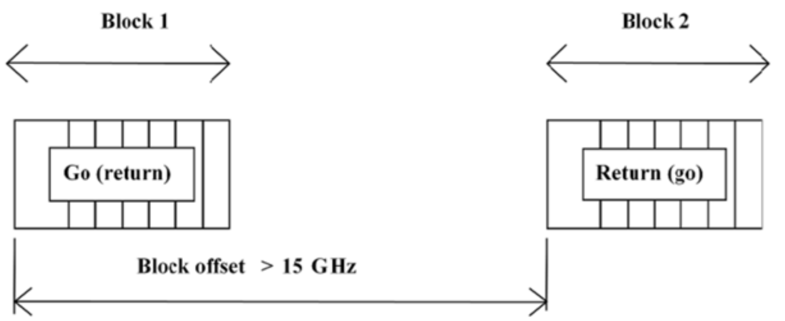


**Figure 20: Paired blocks FDD examples for symmetric go-return channel size**

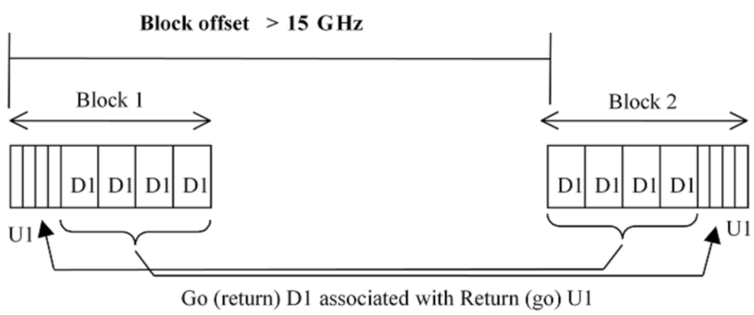


**Figure 21: Paired blocks FDD examples for asymmetric go-return channel size**

The flexible spectrum management allowed by fFDD can provide different advantages for national administrations in assigning spectrum resources to operators in both cases of traditional link-by-link licensing and block licensing [i.11]:

- not all parts of a frequency band could be available in some administration's domain, so different duplex steps would be necessary in different countries;
- interference reduction would be facilitated by having the possibility to assign the different channels to different locations in a more flexible way;
- the possibility to define the go and return channels in an asymmetric way allows an efficient mapping between transport capacity and different access needs in terms of downlink and uplink traffic;
- there is not a part of the spectrum that, being not FDD paired, is to be assigned as TDD or to be left as spare.

## 8.4 Full duplex

A Full Duplex (FD) system is one in which the transmission and reception in both directions of a link can be done at the same frequency and time. The separation between the two communication directions can be made based on dimensions other than time and frequency:

- space separation (e.g. separated TX and RX antennas);
- polarization separation (XPIC);
- separation in the digital domain (e.g. code division).

The main issue when dealing with a full duplex system is the self-interference, that is the possibility to get the signal transmitted from one unit to be received by the same unit; this could be due to different interference paths, as shown in Figure 22:

- local coupling between TX and RX antennas;
- reflections from the environment;
- backscattering by rain.

The local coupling between TX and RX antennas is limited by a proper geometrical separation; for example, measurements at D band indicated over 70 dB isolation with a few cm separation between TX and RX antennas (see Figure 15).

Self-interference due to reflections or scattering can be compensated by proper cancellation algorithms in the digital domain, leveraging on the fact that the TX signal is known at the same radio unit.

Different interference mechanisms can happen at network level in case the same frequency is used by different full duplex radio links operating in the same area. An example is given by a hub site with several PtP links, where different paths of interference across links can happen, as shown in Figure 23 and Figure 24:

- between TX and RX antennas of different links on the same pole (local path);
- between local and remote ends of different links;
- between remote ends of different links (over-reach).

This kind of interference across different links is to be handled by proper radio planning, dealing with the angular separation among the different links.

It is important to consider that in systems operating at mmW the main beam is narrower than at lower frequencies somehow easing the angular separation of the different radio links.

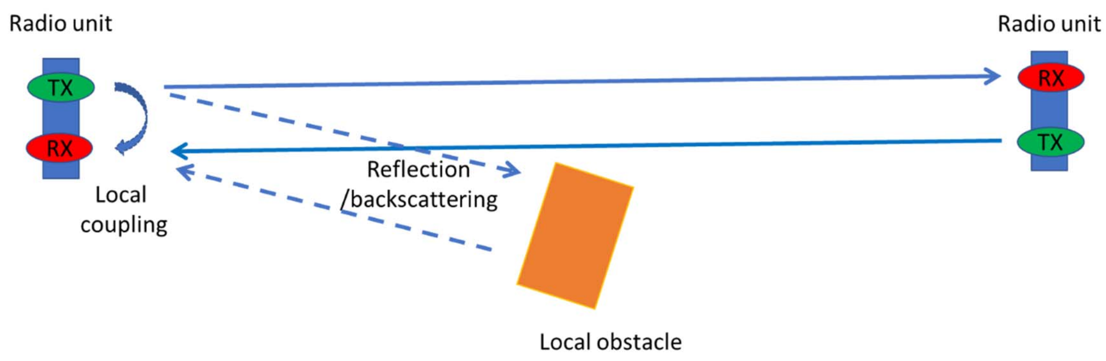


**Figure 22: Self-interference within one FD link**

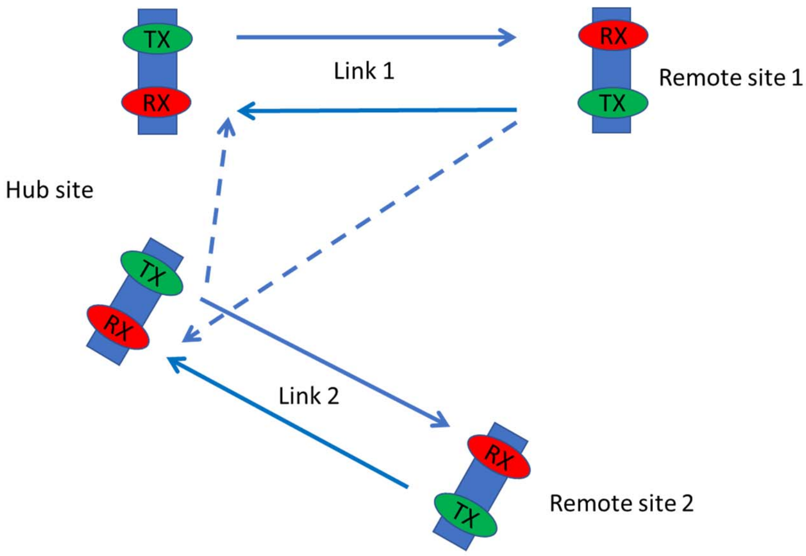


**Figure 23: Cross-link interference between different FD links (local to local, remote to local)**

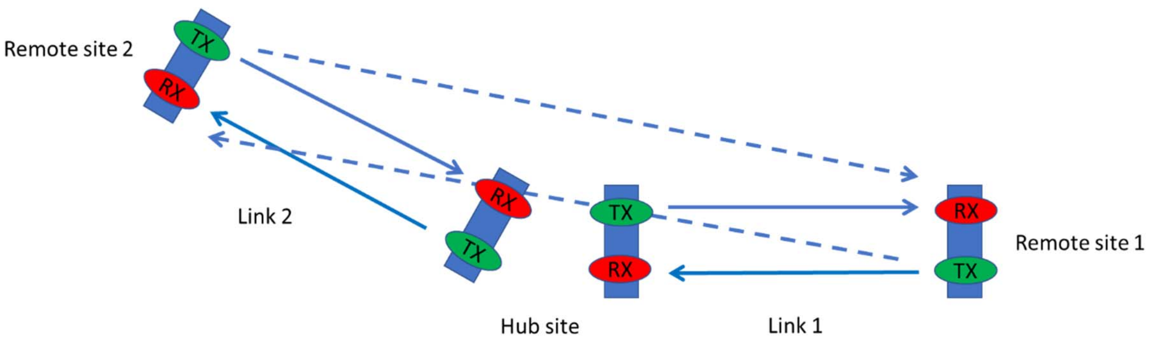


**Figure 24: Cross-link interference between different FD links (remote to remote, over-reach)**

# 9 Implications of integrated antennas on system requirements

## 9.1 Systems with equivalent virtual antenna connector

Even if the antenna is non-detachable from the equipment, there are cases in which an equivalent antenna connector can be defined, by measuring the EIRP and going back to the transmitted power by means of the antenna gain declared by the manufacturer and/or calculated by means of equations.

In general systems with one beam, either fixed or just steering within a limited angle (e.g. < 5°) for sway compensation and alignment tracking purpose, do have a well-defined antenna gain.

In this case the requirements can still be defined at the virtual connector provided that the antenna gain is declared or calculated, even if the measurements for conformance are to be done on the full equipment in a radiated way.

For such a kind of systems, already considered within ETSI EN 302 217-2 [i.1] as systems with integral antenna, a proper radiated test suite is to be developed within ETSI EN 301 126 series [i.12], [i.13].

Work is ongoing within ETSI ATTM TM4 in order to develop a proper standard dedicated to systems with integrated antenna, temporarily named as ETSI EN 301 126-4 [i.16].

## 9.2 Systems without equivalent virtual antenna connector

There are cases in which an antenna connector cannot be defined, not even in a virtual way.

Systems providing multiple beams and dynamic beamforming are examples of this category.

In this kind of systems both the requirements and the conformance testing are to be defined in a radiated way. Proper work is ongoing within ETSI ATTM TM4 as stated in the previous clause.

# 10 Implications of integrated antennas on system testing

## 10.1 Test bench for radiated measurements

Systems with integrated antennas will require to have conformance testing done in radiated way.

Such tests are typically performed in anechoic chamber in conditions of either near field or far field, depending on the considered frequency and on the antenna dimension; in general, near field measurements require both phase and amplitude information, involve shorter distances and take longer time, whilst far field measurements require only amplitude information, involve longer distances and take shorter time.

For an antenna dimension D much larger than the wavelength λ, the border between near field and far field is defined in terms of Fraunhofer distance $d_F$:

$$d_F = 2D^2/\lambda$$

Within near field region, measurements are typically done out of the reactive zone immediately adjacent to the antenna, which is defined as $d_r$:

$$d_r = \lambda/2\pi$$

## 10.2 Radiated RX test bench

A possible test bench that can be conceived for radiated type of conformance testing of receiver parameters is shown in Figure 25.

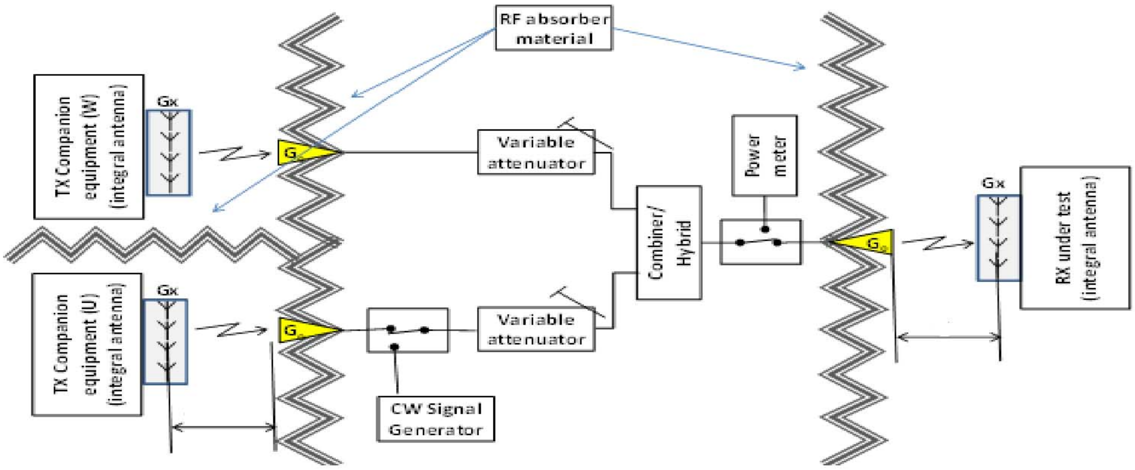


**Figure 25: Test bench for RX radiated conformance verification**

This test setup is extending the traditional setup used for conformance verification in conducted way by using some well-characterized antennas (G0) to transfer system test from the radiated to the conducted environment.

All verification is to be conducted in an anechoic chamber.

Losses and gains of the different sections, dynamic range and sensitivity of the measurement instruments are critical factors, the more critical the higher the operating frequency of the system.

# 10.3 Radiated TX test bench

A possible test bench that can be conceived for radiated type of conformance testing of transmitted power Ptx is shown in Figure 26.

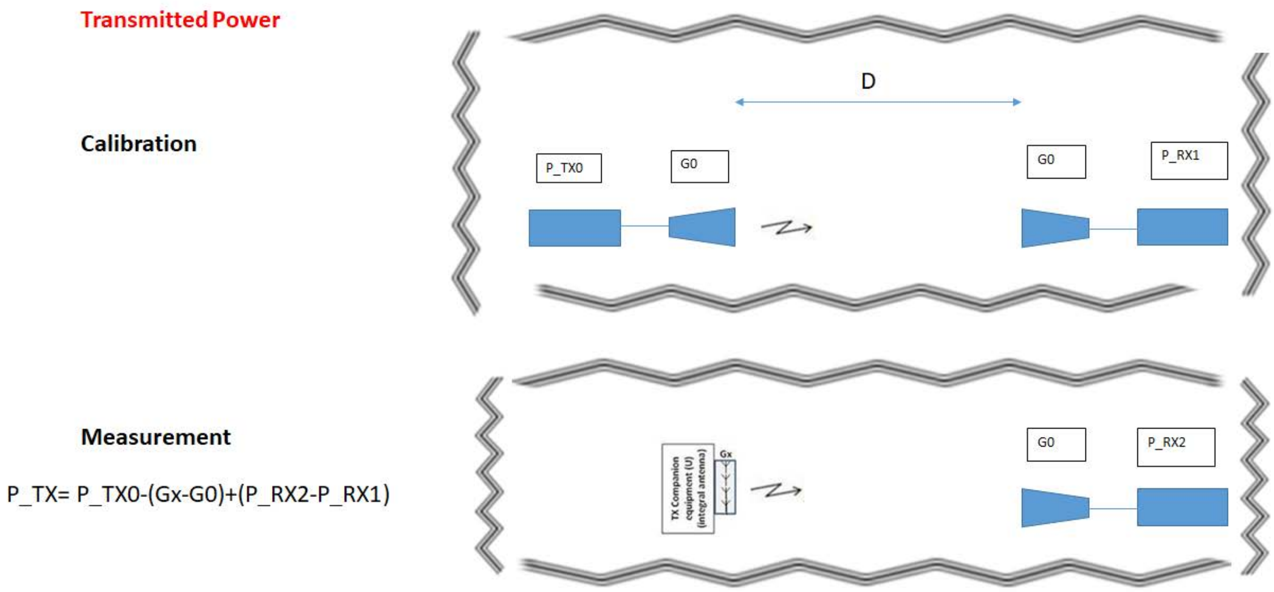


**Figure 26: Test bench for radiated conformance verification of TX power**

In order to measure the transmitted power an initial bench calibration is to be performed to evaluate the propagation loss along the distance D. Once the loss is known, the TX power of the device under test can be measured under the condition of knowing the antenna gain of the device under test Gx (by declaration or by calculation).

The received power would be measured by means of a proper power meter.

A different test bench is to be used when measuring the conformance of the TX signal with the spectrum mask defined in ETSI EN 302 217-2 [i.1]; a possible measurement setup is shown in Figure 27.

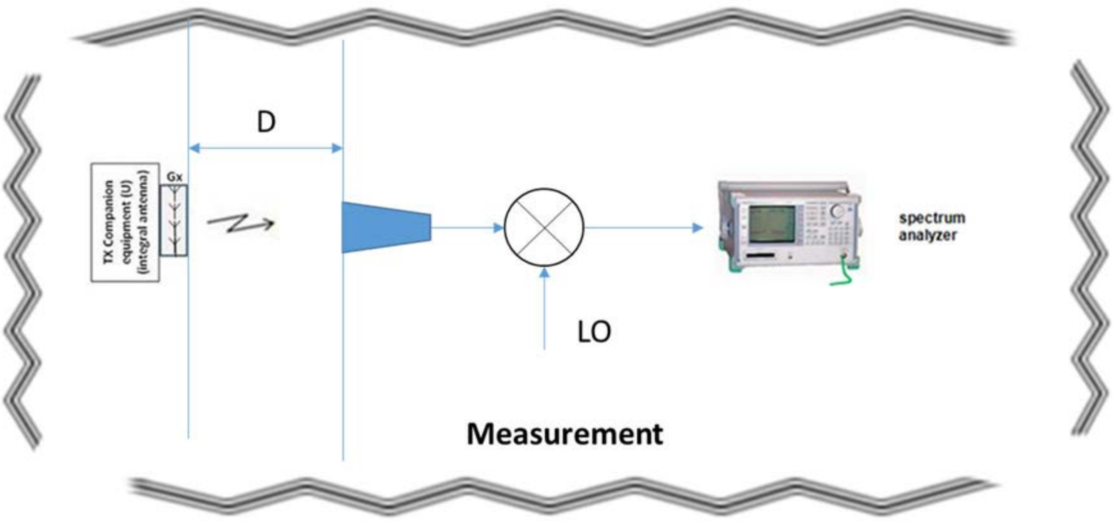


**Figure 27: Test bench for radiated conformance verification of TX spectrum mask**

Due to the limited frequency range of the current spectrum analysers, a mixer is to be interposed between the receiving antenna and the instrument; the linear range of the mixer is key in defining the dynamic range over which the spectrum mask can be verified, together with the noise floor of the spectrum analyser.

Just to understand the values at stake, an available commercial mixer dedicated to interface a D band signal to a spectrum analyser shows a typical 1 dB compression point input power P_1 dB = -3 dBm. A proper back-off is to be maintained from this value in order to avoid having the measurement limited by the nonlinearities (spectral regrowth) of the mixer.

# 11 Conclusions

The traditional antenna used in MW radio links for Fixed Service is a passive detachable one, where system requirements are defined and verified at the antenna connector; the antenna is characterized by parameters like gain, bandwidth and loss and represented by its radiation pattern in space.

Harmonised standards have been developed at ETSI for PtP [i.1] and PtMP [i.2] systems within this logical frame, where the antenna part is dealt with in related ETSI standards [i.3], [i.4].

Antenna technology is evolving in different directions:

- on one side in the traditional path with the target to achieve higher directivity and lower sidelobes to allow a greater system gain and a better coexistence with other systems, both within Fixed Service (intra-service) and with other services (inter-service);
- on alternative directions by investigating new architectures employing active antennas or separated TX and RX antennas.

Innovation in passive, detachable antenna has directed towards ever improving directivity according to progressively more stringent antenna masks as defined by ETSI standards ([i.3], [i.4]), going in time from class 1 to class 4 types for PtP systems and from DN1 to DN5 for PtMP systems and possibly over with the target of improving the efficient use of spectrum.

When going towards frequencies in the mmW range the increasingly shorter wavelength makes **antenna integration into the equipment** feasible and advantageous from both technical and cost sides. In particular when considering D band (130 - 174,8 GHz range) the possibility to design a compact radio unit with integrated antennas has been already demonstrated with some prototypes and several research activities are ongoing on the subject. One prototype with passive, non-detachable and distinct TX and RX antennas was deployed in Milan in November 2016 for propagation investigations in D band [i.5]. Another prototype with active, integrated antennas was developed within the Horizon 2020 framework as well [i.6]. Apart from eliminating the need for a duplex filter, an **architecture with separated TX and RX antennas** opens the way towards innovative duplexing schemes such as flexible FDD (fFDD), where the frequency separation between the go and return channels of a radio link can be flexibly defined in order to optimize the efficient use of spectrum [i.11], or even Full Duplex (FD), where the spectral efficiency can be doubled.

A great push towards the development of innovative antenna systems is coming from the introduction into IMT-2020 of Active Antenna Systems (AAS), which employ antenna array structure with active elements within the antenna in order to control the amplitude and phase of the signals to the single elements of the array. In this way beamforming is possible and the antenna pattern can be adaptively modified in time in order to adapt to the changing propagation conditions and user distribution.

When considering an **integrated non-detachable antenna** where there is no physical antenna connector available, the problem of defining the system requirements and their verification is to be considered.

Even if the antenna is non-detachable from the equipment, there are cases in which an equivalent antenna connector can be defined, by measuring the EIRP and going back to the transmitted power by means of the antenna gain declared by the manufacturer and/or calculated by means of equations.

In this case the requirements can still be defined at the virtual connector provided that the antenna gain is declared or calculated, even if the measurements for conformance are to be done on the full equipment in a radiated way.

On the other side there are cases in which an antenna connector cannot be defined, not even in a virtual way. Systems providing multiple beams and dynamic beamforming are examples of this category. In this kind of systems both the requirements and the conformance testing are to be defined in a radiated way.

In any case for systems with integrated antenna a **paradigm shift is necessary passing from conducted to radiated measurements**. This change requires the measurements to be done in a controlled environment such as an anechoic chamber so to avoid any unwanted influence from the surrounding environment.

This is a new situation for FS equipment to be properly studied, in particular when considering mmW frequencies where the sensitivity of measurement instruments is a critical issue. Work is ongoing within ETSI ATTM TM4 in order to develop a proper standard dedicated to systems with integrated antenna, temporarily named as ETSI EN 301 126-4 [i.16].

# Annex A:
Change history

| Date | Version | Information about changes |
|---|---|---|
| 15-10-2020 | V0.0.1 | First draft in ETSI format |
| 08-02-2021 | V0.0.2 | Following ISG mWT #18 |
| 24-05-2021 | V0.0.3 | Input to ISG mWT #19 |
| 25-05-2023 | V0.0.4 | Input to ISG mWT #25 |
| 29-05-2025 | V0.0.5 | Stable draft |

# History

| Document history | | |
|---|---|---|
| V1.1.1 | August 2025 | Publication |
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