TSG-RAN Working Group 4 (Radio) meeting #95-ER4-2008917

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**Source:** Ericsson

**Title:** TP to TR 38.820: Addition of antenna parameter selection guideline in subclause 7.2

**Agenda item:** 9.2.6.2

**Document for:** Approval

# Introduction

At the last RAN4 meeting (RAN4#94bis-E) array antenna parameters relevant for the frequency range close to 10 GHz was discussed. It was noticed that TR 38.820 describes some typical array antenna topologies to consider for 7 to 24 GHz. However, the current technical information in TR 38.820 does not describe fundamental relations between physical antenna characteristics such as element beamwidth and element separation. This information is essential when parameters is defined for a specific antenna topology and architecture and later mapped towards the array antenna model used by RAN4 and other bodies.

In this contribution we summarize the array antenna model used in RAN4 and add some example parameters to show some basic relations between parameters with the intension to simplify and stimulate work in coming WIs to define RF core requirements.

In this contribution a text proposal for TR 38.820, subclause 7.2 [1] with additional technical background for how to determine antenna parameters for different array geometries is prepared. The text proposal is attached at the end of the contribution and is presented for approval.

This is a revised version of R4-2006925. The changes are summarized as;

1. The definition of number of elements is clarified, instead of N, now referring to MxNx2.
2. Addition of relevant antenna model symbols in symbol section, subclause 3.2.
3. Clarification on parameter selection when sub-arrays is modelled.
4. Alignment with deployment scenarios used in section 5.
5. In parameter selection procedure text not relevant for the antenna model is removed.
6. Correction of “beam width product” spelling.
7. The technical background for the model was changes according to feedback.

# Discussion

When RF core requirements and conformance test requirements for AAS BS was developed by 3GPP RAN4 an parameterized array antenna model was developed. The antenna model together with some general parameters is described in TR 37.840 [3]. The model is also adopted by ITU-R for sharing studies and is documented in ITU-R recommendation M.2101 [2].

In Table 2-1, the parameters used by the model are listed. Based on AAS base station architecture and intended deployment scenario, different parameters will be used to model the base station.

**Table 2-1: Parameters**

| **Parameter** | **Symbol** | **Unit** |
| --- | --- | --- |
| Front to back ratio | *Am* | dB |
| Side lobe suppression | *SLAv* | dB |
| Horizontal HPBW | *3dB* | Degrees |
| Vertical HPBW | *3dB* | Degrees |
| Element peak gain | *GE,max* | dBi |
| Element loss | *LE* | dB |
| Number of columns and rows | *(M, N)* | Integer |
| Horizontal element separation | *dh* | m |
| Vertical element separation | *dv* | m |
| Electrical down-tilt angle | *etilt* | Degrees |
| Electrical scan angle | *escan* | Degrees |

The array antenna model uses a spherical coordinate system, where the **-angle is defined as the angle from the antenna aperture plane to the propagation direction vector and the **-angle is the angle between the normal to the antenna aperture plane and the projection of the propagation direction vector onto *x/y* plane. Where a Cartesian coordinate system *(x, y, z)* is located with the *y/z*-plane in the antenna aperture plane. Hench, the *x*-axis direction or bore-sight direction can be expressed in spherical angles as (**,**) = (90,0) degrees.

The model was intentionally created to model the array response in the half-sphere around the *x*-axis. Hence, the modelled characteristics in the backward direction should not be used for scientific conclusions. The model supports one linear polarization; hence the effects of dual polarized system needs to be accounted for outside the antenna model.

The parameterized antenna model is built around array antenna model where the element factor, array factor and linear phase progressing is characterized as described by equations in Table 2-2.

**Table 2-2: Array antenna model**

| **Description** | **Equation** | **Unit** |
| --- | --- | --- |
| Element Radiation Pattern |  | dBi |
| Element peak gain | , where the peak directivity *DE,max*is calculated from given values on *3dB, 3dB, dh* and*dv* | dBi |
| Composite Radiation Pattern | , where | dBi |

To conserve computing time and complexity it the model created so that the element is gain normalized, instead of the composite array pattern.

As a consequence of how the model is created, parameters cannot be selected arbitrary, since parameters are dependent on each other. The intension with the model is to model realized gain patterns correctly without full pattern directivity normalization. To model absolute gain, parameters must be selected carefully, if not the model produces a nonphysical gain response.

When array antenna parameters are selected for the array antenna model it is preferable to consider physical aspects such as the gain/area relation and gain/beamwidth relations by checking following aspects in given order;

1. Select a deployment scenario suitable for the base station. The deployment scenario will give the appropriate coverage range for the horizontal domain and vertical domain.
2. From the coverage ranges and the inter cell distance the required antenna gain can be determined, from which the array antenna geometry can be determined in terms of number of vertical rows (*M*), the number of horizontal columns (*N*).
3. From the coverage ranges the array antenna steering capability can be determined in terms element separations (*dv*, *dh*).
4. From the given array lattice the element parameters can be considered with respect to the given area for a single element. The element peak gain (*GE,max*) and half power beamwidth product (*3dB3dB*) are depend on each other and must be selected together to maintain accurate model gain response. Also, the element loss factor (*LE*) needs to be included when the element peak gain is determined.
   1. Check the peak element directivity (*DE,max*) with the unit area available for a single element in the array lattice, as described in Eq. 2-1.
   2. Check the peak element directivity (*DE,max*) with the half-power beam with product (*3dB3dB*), as described in Eq. 2-2.
5. From given parameters calculate the peak element directivity (*DE,max*), as described in Eq. 2-3.

From antenna theory the peak element directivity assuming no losses for a given antenna aperture area can be expressed as:

(Eq. 2-1)

Also, the peak element directivity for a given wide symmetrical beam can be approximated by:

(Eq. 2-2)

Depending on the element characteristics the relation between element peak gain and the half power beam width product is different as described in [4]. If a sub-array structure is considered another value of the numerator in Eq. 2-2 must be considered. The numerator in expression in Eq. 2-2 is selected for symmetrical wide beam pattern suitable for single elements.

To be exact it is recommended to select element parameters, where the peak element gain is determined by calculating the directivity from a given geometry including beam widths. The element directivity can be calculated based on the pattern described by Table 2-1 assuming that *GE,max*is equal to 0 dBi. The element peak directivity is calculated in dBi as:

(Eq. 2-3)

, where *AE(,)* is defined in linear scale as:

(Eq. 2-4)

In Table 2-3, some example parameters sets are listed to show the relation between induvial parameters within a set and between different sets.

**Table 2-3: Example array antenna geometries**

| **Set** | ***(M, N)*** | ***dv***  **(m)** | ***dh***  **(m)** | ***3dB***  **(deg.)** | ***3dB***  **(deg.)** | ***GE,max***  **(dBi)** | **Candidate**  **for deployment** | **Note** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | (8, 8) | 0.5 | 0.5 | 90 | 90 | 5.5 | Macro, Urban  Macro, Sub-urban  Micro, Urban |  |
| 2 | (8, 8) | 0.7 | 0.5 | 70 | 90 | 6.2 | Macro, Sub-urban |  |
| 3 | (4, 8) | 0.9 | 0.5 | 54 | 90 | 7.1 | Macro, Sub-urban | 2x1 sub-array |
| 4 | (4, 8) | 1.4 | 0.5 | 40 | 90 | 8.2 | Macro, Rural | 2x1 sub-array |
| 5 | (4, 8) | 1.8 | 0.5 | 30 | 90 | 9.4 | Macro, Rural | 2x1 sub-array |

As shown in the example, different parameter sets are mapped to different deployment scenario. For the example given in Table 2-3, it was assumed that the element loss factor (*LE*) was 2.0 dB.

# Conclusion

In this contribution we have summarized the array antenna model and described how antenna model parameters can be determined. Also, some example parameters sets have been created to map towards different antenna topologies.

A text proposal has been created to TR 38.820 [1] with some additional technical background information about the antenna topologies relation to the array antenna model parameters. At the end on this contribution a text proposal for TR 38.820, subclause 7.2 is attached for approval.

# References

[1] R4-2005740, “draft TR 38.820 v130”, Huawei

[2] M.2101, “RecommendationITU-RM.2101-0; Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies”, ITU-R

[3] TR 37.840, “Study of Radio Frequency (RF) and Electromagnetic Compatibility (EMC) requirements for Active Antenna Array System (AAS) base station”, 3GPP

[4] W. L. Stutzman, "Estimating directivity and gain of antennas," in IEEE Antennas and Propagation Magazine, vol. 40, no. 4, pp. 7-11, Aug. 1998, doi: 10.1109/74.730532, URL: <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=730532&isnumber=15753>

TEXT PROPOSAL for clause 2

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[65] W. L. Stutzman, "Estimating directivity and gain of antennas," in IEEE Antennas and Propagation Magazine, vol. 40, no. 4, pp. 7-11, Aug. 1998, doi: 10.1109/74.730532, URL: <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=730532&isnumber=15753>

TEXT PROPOSAL for clause 3.2

## 3.2 Symbols

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

BWChannel BS channel bandwidth

BWSSB Bandwidth of the SSB

COff Isolation in OFF state

Fmax Measure of the achievable power gain

Ft Cut-off frequency

IMF Industrial Margin

Psat Saturated output power

RON Losses in ON state

xFR Integer representing the BS frequency range

AA Composite antenna array pattern in dB

AE Array element pattern in dB

Am Front-to-back ratio in dB

SLAv Side-lobe suppression in dB

3dB Vertical half power beam width in degrees

3dB Horizontal half power beam width in degrees

GE,max Element peak gain in dB

LE Element loss in dB

dh Horizontal element separation

dv Vertical element separation

 Horizontal angle (defined between -180° and 180°).

 Vertical angle of the signal direction (defined between -0° and 180°, 90° represents the direction perpendicular to the antenna array)

TEXT PROPOSAL for subclause 7.2:

### 7.2.3 Antenna topologies

The AA consists of MxNx2 antenna elements placed is a certain lattice. The signals from the AA is mapped in the RDN creating different antenna topologies as shown in figure 7.2.3-1. The RDN mapping is creating sub-arrays, where the radiating characteristics of a sub-array is different to single antenna elements (AE).



Figure 7.2.3-1: Example RDN mappings

Depending on intended coverage scenarios different types of RDN mappings are foreseen for the frequency range 7 to 24 GHz. For *BS type 1-H* and *BS type 1-O* and *BS type 2-O*, the OTA RF characteristics defined for requirement set category set H and requirement set category O is declared by the base station manufacturer in terms of full array capability as well as sub array or element capability, see TS 38.141-2 [6], clause 4.6.

In Table 7.2.3-1, some example parameters sets are listed to show the relation between individual parameters within a set and between different sets.

**Table 7.2.3-1: Example array antenna geometries**

| **Set** | ***(M, N)*** | ***dv***  **(m)** | ***dh***  **(m)** | ***3dB***  **(deg.)** | ***3dB***  **(deg.)** | **Candidate**  **for deployment** | **Note** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | (8, 8) | 0.5 | 0.5 | 90 | 90 | Urban Macro  Sub-urban Macro  Urban Micro |  |
| 2 | (8, 8) | 0.7 | 0.5 | 70 | 90 | Sub-urban Macro |  |
| 3 | (4, 8) | 0.9 | 0.5 | 54 | 90 | Sub-urban Macro | 2x1 sub-array |
| 4 | (4, 8) | 1.4 | 0.5 | 40 | 90 | Rural Macro | 2x1 sub-array |
| 5 | (4, 8) | 1.8 | 0.5 | 30 | 90 | Rural Macro | 2x1 sub-array |

The element separations *dv* and *dh* is the distance between elements in the array antenna. The RDN can be used to create sub-arrays to optimize coverage. When sub-arrays are modelled, parameters are selected to model the sub-array as a radiating element, as exemplified in Table 7.2.3-1.

### 7.2.4 Array Antenna model

In Table 7.2.4-1, the parameters used by the parameterized array antenna model are described. Based on AAS base station architecture and intended deployment scenario, different parameter sets are required to model an AAS base station.

**Table 7.2.4-1: Parameters**

| **Parameter** | **Symbol** | **Unit** |
| --- | --- | --- |
| Front to back ratio | *Am* | dB |
| Side lobe suppression | *SLAv* | dB |
| Horizontal HPBW | *3dB* | Degrees |
| Vertical HPBW | *3dB* | Degrees |
| Element peak gain | *GE,max* | dBi |
| Element loss | *LE* | dB |
| Number of columns and rows | *(M, N)* | Integer |
| Horizontal element separation | *dh* | m |
| Vertical element separation | *dv* | m |
| Electrical down-tilt angle | *etilt* | Degrees |
| Electrical scan angle | *escan* | Degrees |

The parameterized antenna model is built around array antenna model where the element factor, array factor and linear phase progressing is characterized as described by equations in Table 7.2.4-2.

**Table 7.2.4-2: Array antenna model**

| **Description** | **Equation** | **Unit** |
| --- | --- | --- |
| Element Radiation Pattern |  | dBi |
| Element peak gain | , where the peak directivity *DE,max*is calculated from given values on *3dB, 3dB, dh* and*dv* | dBi |
| Composite Radiation Pattern | , where | dBi |

To conserve complexity the model is created so that the element is gain normalized, instead of the composite array pattern. As a consequence, parameters cannot be selected arbitrary, since parameters are dependent on each other. The intension with the model is to model absolute gain patterns correctly without full pattern directivity normalization. To model absolute gain, parameters must be selected carefully, if not the model produces nonphysical and incorrect gain response.

When array antenna parameters are selected for the array antenna model it is preferable to consider physical aspects such as the gain/area relation and gain/beamwidth relations by checking following aspects in given order;

1. The deployment scenario will give the appropriate coverage range for the horizontal domain and vertical domain.
2. From the coverage ranges and the inter cell distance the required antenna gain can be determined, from which the array antenna geometry can be determined in terms of number of vertical rows (*M*), the number of horizontal columns (*N*).
3. From the coverage ranges the array antenna steering capability can be determined in terms element separations (*dv*, *dh*).
4. From the given array lattice the element parameters can be considered with respect to the given area for a single element. The element peak gain (*GE,max*) and half power beamwidth product (*3dB3dB*) are depend on each other and must be selected together to maintain accurate model gain response. Also, the element loss factor (*LE*) needs to be included when the element peak gain is determined.
   1. Check the peak element directivity (*DE,max*) with the unit area available for a single element in the array lattice, as described in Eq. 7.2.4-1.
   2. Check the peak element directivity (*DE,max*) with the half-power beam width product (*3dB3dB*), as described in Eq. 7.2.4-2.
5. From given parameters calculate the peak element directivity (*DE,max*), as described in Eq. 7.2.4-3.

From antenna theory the peak element directivity assuming no losses for a given antenna aperture area can be expressed as:

(Eq. 7.2.4-1)

Also, the peak element directivity for a given wide symmetrical beam can be approximated by:

(Eq. 7.2.4-2)

Depending on the element characteristics the relation between element peak gain and the half power beam width product is different as described in [65]. If a sub-array structure is considered another value of the numerator in Eq. 7.2.4-2 must be considered. The numerator in expression in Eq. 7.2.4-2 is selected for symmetrical wide beam pattern suitable for single elements.

To be exact it is recommended to select element parameters, where the peak element gain is determined by calculating the directivity from a given geometry including beam widths. The element directivity can be calculated based on the pattern described by Table 7.2.4-1 in dBi as:

(Eq. 7.2.4-3)

, where *AE(,)* is defined in linear scale as:

(Eq. 7.2.4-4)