Project	**IEEE 802.16 Broadband Wireless Access Working Group**
Title	Base Transceiver Station Antenna
Date Submitted	**1999-10-14**
Source	Joel N. Holyoak, Ph.D., Geza Dienes, IEEE Fellow, and Michael R.Wolfe Andrew Corporation 2601 Telecom Parkway Richardson, TX 75082 Voice: (972) 952 – 9866 Fax: (972) 952 – 0077 E-mail: joel.n.holyoak@andrew.com
Re:	This paper is a response to a December 1999 Call for Contributions, for 802.16's Meeting #5 (January 10-14 in Dallas, Texas). This paper is response to a update the paper presented at Meeting #4 that outlined recommendations for Base Transceiver Station Antenna Pattern and Mask equipment design parameters.
Abstract	This document recommends the Radiation Envelope Patterns and gains for the Base Transceiver Station (BTS) Antennas.
Purpose	The purpose of this document it to be included in the appropriate section in the recommendation document.
Notice	
Release	
IEEE Patent Policy	

Base Transceiver Station Antenna Recommendations

Joel N. Holyoak, Ph.D., Geza Dienes, and Michael R. Wolfe
Andrew Corporation

5. Base Transceiver Station (BTS) Antenna

The recommendations for the Base Transceiver Station antenna are meant to augment the overall system design for the Broadband Wireless Access implementation. It is expected that improvements in the ability to create improved patterns in the future will allow system designers additional flexibility. The maximum and minimum values presented in this section are not meant to limit future design capabilities.

5.1. Electrical Characteristics

The two types of BTS antennas, sector and omni-directional, are considered. The specification focuses on sector antennas because the application of omni-direction antennas is minimal and can be better served by the use of two 180^{o} sector antennas. At this time, the patterns have no differentiation based on frequency. Three classes of operation are considered and involve low, moderate, and high interference environments.

	Class 1 – Low Interference Environment	Class 2 – Moderate to High Interference Environment	Class 3 – Very High Interference Environment
User Density	low	Higher	highest
Overlap (with adjacent sectors)	minimal	Increasing	most
Buffer Distance (between potential interfering cells)	large	Limited	none
Concurrent Signals	smallest number	multiple in each sector	most
Frequency Reuse	minimal, if any	Some	significant
Polarization Differentiation	not required	Important	critical

A 0^{o} reference direction shall be defined for each antenna. The radiation characteristics in this standard are all referred to this reference direction.

The co-polar and cross-polar radiation envelopes for both azimuth and elevation shall not exceed the radiation pattern envelopes, RPE(s), for the classes of operation in which they are presented. While an envelope implies a specified maximum and minimum value, maximum and minimum values shall be specified as required to best specify coexistence principles.

5.1.1 Linear Polarization

Only horizontal and vertical polarization shall be included in this specification.

5.1.1.1 Affect on Radiation Pattern Envelop (RPE)

In considering coexistence, the purchaser/system provider needs to factor the AZ and EL RPE's into the required coverage footprint. For purposes of consistency and ease of implementation, the ability to select either horizontal or vertical polarization without the need for concern for differences in the RPE's is considered very important. Hence, the AZ and EL RPE's shall be identical for horizontal and vertical polarized antennas.

5.1.1.2 Minimum Cross-Polar Discrimination (XPD)

The cross-polar discrimination (XPD) sets the difference in dB between the peak of the copolarized main beam and the maximum cross-polarized signal over an angle measured within a defined region. With respect to coexistence, XPD is important not only for discrimination from interference within the local cell but also from adjacent cells. It is recommended that the polarization discrimination be >30 dB.

5.1.1.3 Minimum Cross-Polar Isolation (XPI)

Specification of a minimum cross-polar isolation (XPI) for the BTS antenna implies that the antenna is a dual polarized antenna. Practice is showing that these antennas are being deployed as single polarized units. Hence, there is not a need to define the minimum cross-polar isolation.

5.1.1.4 Inter-Port Isolation

Specification of a inter-port isolation for the BTS antenna implies that the antenna is a dual polarized antenna. Practice is showing that these antennas are being deployed as single polarized units. Hence, for those deployments, there is not a need to define the inter-port isolation.

Should there be an application using a dual polarized BTS antenna, the isolation between the input ports of the dual polarized antenna should be agreed upon between the equipment supplier and the purchaser in line with the overall system design requirements. For guidance, inter-port isolation better than 25 dB is typical.

5.1.1.5 Antenna-to-Antenna Isolation

In practice, sector antennas are being co-located that are directed to the same sector. Such co-location involves two primary configurations. In one case, there are multiple antennas mounted at the same site on the same mounting structure that are directed to the same sector angle. In the second case, there are multiple antennas mounted at the same site on different mounting structures that are directed to the same sector.

Antenna-to-antenna isolation is dependent on factors like site location, mounting configurations, and other system level issues. Even with seemingly uncontrollable factors, there is a need for isolation between the antennas directed to the same sector. For guidance, the antenna-to-antenna isolation for antennas which are co-pointed to the same sector with sector sizes of 90^o and less should be minimally 60 dB.

5.1.2 Radiation Pattern Envelop (RPE)

5.1.2.1 Azimuth Radiation Pattern Envelopes, Sectored

The azimuth radiation pattern envelope is specified in terms a variable α that is ½ the 3 dB beamwidth of the antenna. Sector sizes for these RPE tables range from 15° to 135°. A 180° sector will be considered a special case for use in generation of an omni-directional antenna pattern.

5.1.2.1.1 Class 1 Azimuth RPE

A Class 1 implementation involves a low interference environment. For this case, it is assumed that the antenna pattern of the sector antenna need not be as tight as for a higher interference environment.

5.1.2.1.1.1 Class 1 - Co-Polar Azimuth

The effect of azimuth on improved coexistence involves increasing the steepness of the sidelobe so that there is reduced overlap of the adjacent sectors. While other authorities' specifications specify less steepness in the roll-off, existing technology shows that increased steepness can be achieved. This recommendation promotes the improved technology capabilities and encourages further improvements.

In terms of α, where α equals ½ the 3 dB beamwidth:

Angle off-boresight °	ETSI Recommended Maximum Relative Gain dB	Recommended Maximum Relative Gain dB	Recommended Minimum Relative Gain dB
0	0	0	-3
α		0	-3
α + 5	0		-5
2 * α		-10	
(2 * α) + 5	-10		
135	-12		
3 * α		-20	
155	-15	-25	
180	-25	-25	

A minimum gain is included to guarantee illumination within the sector. Elimination of nulls helps to keep remote stations from needing the base station to transmit using excess power that could affect coexistence.

Note: ETSI values have been included for comparison purposes only and will be excluded when the document is finalized.

5.1.2.1.1.2 Class 1 - Cross-Polar Azimuth

In terms of α, where α equals ½ the 3 dB beamwidth

Angle off-boresight °	ETSI Recommended Maximum Relative Gain dB	Recommended Maximum Relative Gain dB
0	-22	-22
α	-22	-25
α + 15	-25	
3 * α		-25
180	-25	-25

5.1.2.1.2 Class 2 Azimuth RPE

A Class 2 implementation involves a moderate to high interference environment. For this case, it is assumed that the antenna pattern of the sector antenna needs to be as tight as possible to limit interference.

5.1.2.1.2.1 Class 2 - Co-Polar Azimuth

In terms of α, where α equals ½ the 3 dB beamwidth:

Angle off-boresight °	ETSI Recommended Maximum Relative Gain dB	Recommended Maximum Relative Gain dB	Recommended Minimum Relative Gain dB
0	0	0	-5
α - 5			-5
α		0	
α + 5	0		
α + 15	-20		
2 * α		-20	
110	-23		
3 * α		-30	
140	-35		
155		-30	
180	-35	-30	

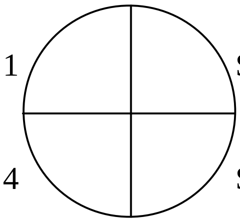
5.1.2.1.2.2 Class 2 - Cross-Polar Azimuth

In terms of α, where α equals ½ the 3 dB beamwidth

Angle off-boresight °	ETSI Recommended Relative Gain dB	Recommended Maximum Relative Gain dB
0	0	-25
α	-25	-30
α + 15	-30	
105	-30	
140	-35	
3 * α		-30
180	-35	-30

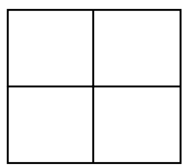
5.1.2.1.2.3 Class 2 – Flat Pattern Considerations

There has been some discussion on the need for a different type of pattern architecture. This architecture provides for a flat pattern throughout the half power azimuth beamwidth. The argument to include a flat-top pattern leads to a discussion of the type of cell architectures that will be deployed. The flat-top pattern is optimized for a circular cell architecture. It has equal power along the radius of the circular cell. The following figure shows the 90^o sectorized circular cell architecture.



The signal strength around the perimeter would be approximately constant under ideal conditions.

A sector design which has patterns similar to those proposed here has $\pm\ \alpha$ as the 3-dB points is better optimized for a square cell structure as shown in the following figure which also has 90^o secorization.



In this case, the distance to the corner is farther than the distance to the sector edge. The proposed pattern better fills the square. In terms of coexistence, the use of a square cell structure would tend to mitigate overlap regions and reduce potential adjacent cell interference.

5.1.2.1.3 Class 3 Azimuth RPE

A Class 3 implementation involves a very high interference environment. For this case, it is assumed that the antenna pattern of the sector antenna needs to be tighter than achieved for Class 2 in order to limit interference. This class is the most important with respect to steepness of the slope at values greater than α. In previous classes, recommended maximum relative gain values were specified at integer multiples of α and at specified angle values added to integer multiples of α. This latter specification has a more pronounced effect at $\alpha = 15^o$ than, for example, $\alpha = 45^o$ for a value specified for angle $\alpha + n^o$ where n = 5, 10, 15. Because of the greater possibilities of interference in Class 3 in adjacent sectors, it is recommended that fixed differences from integer multiples of α not be used but instead multiples including fractional multiples of α be used. The values specified here will need to be modified should improved techniques allow for realizable steeper slopes at the sector boundaries.

5.1.2.1.3.1 Class 3 - Co-Polar Azimuth

In terms of α, where α equals ½ the 3 dB beamwidth:

Angle off-boresight °	Recommended Maximum Relative Gain dB	Recommended Minimum Relative Gain dB
0	0	-7
α	3	
1.1 * α		
1.3 * α	-25	
2 * α	-29	
3 * α	-35	
155	-35	
180	-35	

5.1.2.1.3.2 Class 3 - Cross-Polar Azimuth

In terms of α, where α equals ½ the 3 dB beamwidth:

Angle off-boresight °	Recommended Maximum Relative Gain dB
0	-27
α	-33
3 * α	-33
180	-33

5.1.2.2 Elevation Radiation Pattern Envelopes, Sectored

5.1.2.2.1 Coexistence Issues

Based on a cursory look at the coexistence issues of an elevation radiation pattern, it might appear that the envelope needs only be defined for the angles above the horizon. In other authorities' specifications, this practice is observed. In other sections of this document, system aspects of power control and rain fade attenuation are considered which need certain gains for the angles below the horizon. It is proposed that the maximum radiation pattern envelope be defined above the horizon and the minimum radiation pattern envelope be defined below the horizon. In addition, informative information on the maximum radiation pattern envelope will be given for angles below the horizon.

5.1.2.2.2 Reference Directions

This specification will follow accepted practices for the specification of elevation radiation pattern envelopes that provide for the 0^o angle to be directed overhead, the 90^o angle directed at the horizon, and the 180^o angle directed downward.

5.1.2.2.3 Class 1 Elevation RPE.

A Class 1 implementation involves a low interference environment. For this case, it is assumed that the antenna pattern of the sector antenna need not be as tight as for a higher interference environment.

5.1.2.2.3.1 Class 1 - Co-Polar Elevation

Above the peak of the elevation beam (Note: takes into account that beam tilt may be used):

Angle ^{o}	ETSI Recommended Maximum Relative Gain dB	Recommended Maximum Relative Gain dB
0	-25	-30
50		-30
65		-20
70		-20
75	-15	
83		-3
86		0
90	0	

Below peak of the elevation beam (Note: takes into account that beam tilt may be used).

Angle °	Recommended Minimum Relative Gain dB
90	-3
94	-3
110	-32
130	-80
180	-80

The specification of the minimum gain below the horizon helps to eliminate nulls in pattern that could result in the use of additional power that could affect coexistence.

5.1.2.2.3.2 Class 1 - Cross-Polar Elevation

Angle °	ETSI Recommended Maximum Relative Gain dB	Recommended Maximum Relative Gain dB
0	-22	-22
180	-25	-25

Use linear interpolation between limits.

5.1.2.2.4 Class 2 Elevation RPE

A Class 2 implementation involves a moderate to high interference environment. For this case, it is assumed that the antenna pattern of the sector antenna needs to be as tight as possible to limit interference.

5.1.2.2.4.1 Class 2 - Co-Polar Elevation

Above peak of the elevation beam:

Angle °	ETSI Recommended Maximum Relative Gain dB	Recommended Maximum Relative Gain dB
0	-25	-33
65		-33
73		-27
75	-15	
86.7		-14
88.7		-2
89.4		0
90	0	0

Below peak of the elevation beam:

Angle °	Recommended Minimum Relative Gain dB
90	
90.3	-0.5
90.8	-2
91.3	-4
93	-17
95	-22
100	-22
109.5	-28
116	-28
117.5	-33
120	-33
120	-80

5.1.2.2.4.2 Class 2 - Cross-Polar Elevation

Angle ^{o}	ETSI Recommended Maximum Relative Gain dB	Recommended Maximum Relative Gain dB
0	-25	-25
180	-35	-35

Use linear interpolation between limits.

5.1.2.2.5 Class 3 Elevation RPE

A Class 3 implementation involves a very high interference environment. Clearly, the elevation pattern can and must be used to reduce interference to satellites. The characteristics of the Class 2 antenna appear sufficient to eliminate interference with satellites. The use of elevation for discrimination between adjacent cells by narrowing the elevation beamwidth of the antenna is questionable. For example, with a tower height of 60 m and a cell radius of 5 km, the angle to the cell edge is about 0.688^{o} down from the horizon. The angle to the center of a same size adjacent cell is about 0.344^{o} down from the horizon. Hence, there is only 0.344^{o} difference for discrimination from the edge of the cell to the center of the adjacent cell. Implementations for sector antennas achieve elevation beamwidths of about 1.5^{o} to 3^{o}. Because it is not possible to achieve better interference performance with adjacent cells by the use of the elevation patterns, the Class 2 RPE limits shall be used also in Class 3.

5.1.2.2.5.1 Class 3 - Co-Polar Elevation

See Class 2 values.

5.1.2.2.5.2 Class 3 - Cross-Polar Elevation

See Class 2 values.

5.1.2.3 Elevation Radiation Pattern Envelopes, Omni-Directional

In review of the available omni-directional antennas for these frequency ranges, there are a limited number of true omni-directional antennas. These units have a restricted mounting characteristic in that they need to be at the top of the mounting structure and cannot accept blockage associated with mounting the antenna on the side of the mounting structure. To avoid these mounting limitations, omni-directional patterns are formed by the use of multiple sector antennas. To minimize the complexity in mounting and the resulting differences in RPE's based on mounting, it is recommended that a omni-directional pattern be formed by mounting two 180^{o} sector antennas in a back-to-back configuration. It should be noted that when two 180^{o} sector antennas are used to emulate an omni-directional antenna, typically different polarizations are used for the two antennas. Hence, the polarization of a true omni-directional antenna will not be the same with respect to polarization for the two back-to-back antennas. Likewise, there will be some overlap of the two patterns that will result in different RPE values in the overlap region.

5.1.3 Minimum Boresight Gain

The BTS sector antenna boresight gain shall exceed the boundaries defined in the following table for all frequencies in the specified frequency range.

Sector Angle Degrees	ETSI Specified Boresight Minimum Gain dB	Recommended Boresight Minimum Gain Class 1 - dBi	Recommended Boresight Minimum Gain Class 2 – dBi	Recommended Boresight Minimum Gain Class 3 - dBi
15	16			
30	15.5			
45	14.5	18	20.8	23.5
60	13.5			
90	12.5	15	18	21
135	11			
180	9.5	12	15	18

Note: The gains presented in the table above are affected by the antenna efficiency. For guidance, the difference between antenna directivity and gain should not exceed 1 dB.

5.1.4 VSWR

The maximum VSWR should be agreed upon between the equipment supplier and purchaser in line with the overall system design requirements. For guidance, antennas with a VSWR in the range of 1.9 to 1.1 are practical with 1.5 being the typical value.

5.1.5 Passive Intermodulation (PIM)

Co-location is one of the factors that contributes to Passive Intermodulation (PIM) performance. Non-TDMA Point to Multi-Point (P-MP) access methods also affect PIM performance of the antenna due to the number of simultaneous carriers which need to be taken into account. In such cases, a passive intermodulation performance should be agreed upon between the equipment supplier and purchaser in line with the overall system design requirements. For guidance, PIM product limits can often exceed –100 dBc.

5.2. Mechanical Characteristics

5.2.1 Temperature and Humidity

The antennas shall be designed to operate within a temperature range of -45^{o}C to $+45^{o}$C with relative humidity from 1 to 100%.

5.2.2 Wind and Ice Loading

Wind loading as specified in this document for the BTS relates to mechanical deformations that would cause the radiated pattern to be altered and, hence, affect the coexistence characteristics. Ice loading as specified in this document for the BTS relates to the electro/mechanical effects that would case the radiated patter to be altered and, hence, affect the coexistence characteristics. The deviation of the antenna main beam axis should not be more than 0.5 degrees in either the azimuth or elevation under the following conditions. The antennas should be designed to meet wind and ice survival ratings specified under the following conditions:

Capability	Wind Velocity mi/hr	Ice Load density 43.6 lbs/ft^3
Operational	70	1 in
Survival	125	1 in

Note: Hoarfrost is defined with density 19 lbs/ft^3, rime ice is defined between 19 and 56 lbs/ft^3, and glaze ice is defined as 56 lbs/ft^3. The specified value for density is about 66% of the difference between hoarfrost and glaze.

5.2.3 Water Tightness

Water tightness is important in eliminating unwanted attenuation that would not necessarily be uniform over the antenna aperture and could change the pattern and non-uniformly reduce the distance over which the BTS would operate. For example, should radiating power be increased for part of the pattern to overcome water in the antenna, the power applied to other parts of the pattern could be larger than required and could cause interference problems resulting in coexistence issues.

5.3. Miscellaneous Additional Elements

5.3.1 Radomes

Antennas adopting radomes shall conform to the absolute gain and radiation pattern values stipulated in the sections above with the radome in place.

5.3.2 Heaters

For antennas adopting the use of heaters to avoid icing on the radomes, these antennas shall conform to the absolute gain and radiation pattern values stipulated in the sections above with the heaters in place.

5.3.3 Labeling

With respect to coexistence, labeling aids in the proper installation of the antenna. Proper labeling aids in installing the correct antenna with the correct radiation characteristics. Antennas should be clearly identified with a weather-proof and permanent label(s) showing the antenna type, antenna frequency range, antenna polarization, and, serial number(s). If should be noted that integrated antennas may share a common label with the outdoor equipment.

5.3.4 Mechanical Tilting Assembly

The sector antennas described in this specification typically have a wide azimuth pattern and an narrow elevation pattern. With respect to coexistence, the adjustment of the elevation and the cant of antenna is deemed more important that a precision adjustment of the azimuth. The mechanical tilting assembly shall accommodate adjustments in elevation and cant. The adjustment ranges shall allow for the following:

Adjustment	Adjustment Range
Elevation	$\pm 5^{o}$
Cant	$\pm 2^{o}$

.

For those applications where a precision azimuth adjustment is deemed necessary, an adjustment range of $\pm 2^{o}$ is recommended.