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Title	**IEEE 802.16.2, Recommended Practices to Facilitate the Coexistence of Broadband Wireless Access (BWA) Systems, Revision 2**
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Re	This is a working document leading toward “Recommended Practices to Facilitate the Coexistence of Broadband Wireless Access (BWA) Systems,” authorized under IEEE PAR 802.16.2.
Abstract	IEEE 802.16.2 [Recommended Practices to Facilitate the Coexistence of Broadband Wireless Access (BWA) Systems], specifies the design, installation and test parameters for Broadband Wireless Access systems pertinent to coexistence. This document provides coexistence support for systems designed to be compliant with 802.16.1 standards.
Purpose	This is a working document to be reviewed by Working Group 802.16 prior to Session #6. It will serve as the basis for our discussions at that meeting and for further development. **This working document has not been approved or voted upon**.
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Release	
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IEEE 802.16.2: Recommended Practices to Facilitate the Coexistence of Broadband Wireless Access (BWA) Systems, Revision 2

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1. Introduction

This document provides guidelines for minimizing interference in Broadband Wireless Access (BWA) systems. Pertinent coexistence issues are addressed and recommended engineering practices provide guidance for system design, deployment, coordination and frequency usage. The document covers the 10 to 66 GHz frequencies in general, but is focused on the range of 20 to 40 GHz.

1.1 Scope

This document provides recommended practices for the design and coordinated deployment of Broadband Wireless Access (BWA) systems to minimize interference so as to maximize system performance and/or service quality. The intent of this document is to define a set of consistent design and deployment recommendations for BWA systems. These recommendations, if followed by manufacturers and operators, will allow a wide range of equipment to coexist in a shared environment with minimum mutual interference. This practice provides recommendations in three specific areas. First, it recommends limits for both in-band and out-of-band emissions from BWA transmitters through parameters including radiated power, spectral masks and antenna patterns. Second, it recommends tolerance levels for certain receiver parameters, including noise floor degradation and blocking performance, for interference received from other BWA systems as well as from other terrestrial and satellite systems. Third, it recommends band plans, separation distances, and power spectral flux density limits to facilitate coordination and to enable successful deployment of BWA systems with tolerable interference. The scope includes interference between systems deployed across geographic boundaries in the same frequency band and systems deployed in the same geographic area in different frequency bands (including different systems deployed by a single license-holder in sub-bands of the licensees authorized bandwidth). This document emphasizes coexistence practices for Point-to-Multipoint systems. The scope does not cover coexistence issues due to intra-system frequency re-use within the operator's licensed band, and it does not consider the impact of interference created by BWA systems on non-BWA terrestrial and satellite systems.

1.2 Order of Precedence and Assumptions

(a) In the event that local regulations have more stringent requirements than those contained within this document, then local regulations take precedence.

(b) This document was developed based on BWA equipment which will conform to 802.16.1, but is intended to be generally applicable to all broadband wireless systems.

1.3 Definitions

***Authorised Band**:* The band over which the regulator permits the license holder to operate transmitters.

Basic Trading Area (BTA): A geographic area of the United States for which LMDS licenses spectrum licenses are issued. (BTAs are defined in Rand-McNaley maps for commercial trading.)

Digital modulation: The process by which some characteristic (frequency, phase, amplitude or combinations thereof) of a carrier frequency is varied in accordance with a digital signal. For complex digital modulation, either the carrier state (phase, freqeuncy and/or amplitude) is changed multiple times during an information bit interval (spread spectrum), or the state of multiple carriers is changed at intervals much less frequent than a bit interval (e.g., OFDM). Digital modulation is characterized by discrete changes of state for the carrier signal rather than continuous changes as in analog modulation.

Equivalent Isotropically Radiate Power (EIRP): The product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna. For purposes of this document, EIRP is expressed in decibels referenced to either 1 milliWatt (dBm) or one Watt (dBW) in the direction of the main antenna beam.

Frequency Ranges**:** For purposes of this document, the following three frequency ranges are defined:

- Range 1: 10 GHz To 23.5 GHz
- Range 2: 23.5 GHz To 43.5 GHz
- Range 3: 43.5 GHz To 66 GHz

Frequency Tolerance: Frequency tolerance is defined with respect to the carrier frequency in the air and is the maximum permissible departure with respect to the assigned frequency of the corresponding characteristic frequency of an emission.

Harmonics*:* Emissions which are an integer multiple of a primary emission frequency. This includes baseband, IF and RF harmonics, which may all appear as sub-modulations of the main carrier.

Necessary Bandwidth: For a given class of emissions, it is the minimum value of the occupied bandwidth sufficient to insure the transmission of information at a rate and with the quality required for the system employed, under specified conditions. This bandwidth includes all signals necessary for the proper functioning of the equipment.

Occupied Bandwidth $\mathbf{B_o}$: For a single carrier, it is the width of a frequency band such that below its lower and above its upper frequency limits, the mean powers radiated are each equal to 0.5% of the total mean power radiated by a given emission. This implies that 99% of the total mean emitted power is within this band, and hence this bandwidth is also known as the 99% bandwidth.

When a multi-carrier modulation (not to be confused with OFDM) uses a common amplifier stage, the occupied bandwidth of this composite transmission is defined as the numeric sum of the individual carrier occupied bandwidths.

> NOTE: This definition applies to most analog and simple digital emissions (QAM, QPSK, etc), but its applicability to other more complex modulation structures (e.g., OFDM, CDMA) is still to be determined.

Out-of-Band Emissions*:* Emissions from the edge of the occupied bandwidth up to 200% of the occupied bandwidth from the edge of the occupied bandwidth. These emissions occur both above and below the main emission

Power Flux Density (pfd): The radiated power flux per unit area expressed as Watts/m^2.

Power Spectral Flux Density (psfd): The radiated power flux per unit bandwidth per unit area. It is often expressed in Watts/MHz/m^2.

Spectrum Disagregation: Some regulators allow a license holder to segregate his spectrum, to permit several operators access to sub-portions of the licensee's authorised band.

Spurious Emissions*:* Emissions greater than 200% of the occupied bandwidth from the edge of the occupied bandwidth.

Unwanted Emissions*:* Comprise out-of-band emissions, spurious emissions and harmonics.

Virtual Block Edge: A reference frequency used as a block edge frequency for testing of unwanted emissions, so as to avoid effects of RF block filters.

Repeaters are generally used to improve coverage to locations where the hub(s) have no line of sight within their normal coverage area(s), or alternatively to extend coverage of a particular hub beyond its normal range.

1.4 Related Standards and Documents

IEEE 802.16.1 "Air Interface Standard for Broadband Wireless Access systems"

ETSI BRAN HIPERACCESS "High PERformance Radio ACCESS System"

ETSI EN 301 213, parts 1-3 "Point to Multipoint DRRS operating in the band 24.5GHz to 29.5GHz" [check exact title]

ETSI DEN/ TM 04097 "MWS in the 40.5GHz to 43.5GHz frequency band" [check exact title]

ETSI EN 301 215 – 1 "Point to Multipoint Antennas: Antennas for point-to multipoint fixed radio systems in the 11GHz to 60GHz band; Part 1: General aspects"

ETSI EN 301 215-2 "Point to Multipoint Antennas: Antennas for point-to multipoint fixed radio systems in the 11GHz to 60GHz band; Part 2: 24GHz to 30GHz"

ETSI EN 301 215-3 [add exact title]

[Add reference to ITU rain fading statistics]

ITU Recommendation F.746-1 "Radio Frequency channel arrangements for fixed services in the range 22.0 GHz to 29.5 GHz"

CEPT Rec. T/R 13-02 "Preferred channel arrangements for the Fixed Services in the range 22.0-29.5 GHz."

[Add reference to Canadian frequency plans]

[Add reference to USA frequency plans for LMDS]

[Add reference to North American EMC specifications]

ITU-R Recommendation F.[AD/9D] "Maximum equivalent isotropically radiated power of transmitting stations in the Fixed Service operating in the frequency band 25.25-27.5 GHz shared with the Inter – Satellite Service."

IEC Publication 154-2 "Flanges for wave guides, rectangular"

[Add relevant spurious emission specifications such as DEN/TM 04040]

ITU-R Rec. F.1191 "Bandwidths and unwanted emissions of digital radio relay systems"

CEPT/ ERC Rec. 74-01 "Spurious Emissions"

[Add any relevant North American spurious emission standards]

RSS 191	"Local Multi Point Communication Systems In The 28 GHz Band; Point-To-Point And Point-To-Multipoint Broadband Communication Systems In The 24 GHz And 38 GHz Bands"
SRSP-324.25	"Technical Requirements for Fixed Radio Systems Operating in the Bands 24.25 - 24.45 and 25.05 - 25.25 GHz"
SRSP-325.35	"Technical Requirements for Local Multipoint Communication Systems (LMCS) Operating in the Band 25.35 - 28.35 GHz" SRSP-338.6 "Technical Requirements for Fixed Radio Systems Operating in the Band 38.6 - 40.0 GHz"
SRSP	"A Radio Advisory Board of Canada Supporting Study Leading to a Coordination Process For Point-To-Multipoint Broadband Fixed Wireless Access Systems in the 24, 28 and 38 GHz Bands"

2. System Overview

Broadband Wireless Access (BWA) is a term referring to a range of fixed radio systems, used primarily to convey broadband services between users' premises and core networks. The term "broadband" is usually taken to mean the capability to deliver significant bandwidth to each user (in ITU terminology, greater than around 1.5 Mbps, though many BWA networks support significantly higher data rates). The networks operate transparently, so users are not aware that services are delivered by radio. There is usually no direct user-to-user traffic. Such connections, if required, are made via a core network.

A typical BWA network supports connection to many user premises within a radio coverage area. It provides a pool of bandwidth, shared automatically amongst the users. Demand from different users is often statistically of low correlation, allowing the BWA network to deliver significant bandwidth-on-demand to many users, with a high level of spectrum efficiency. Significant frequency re-use is employed.

The range of applications is very wide and evolving quickly. It includes voice, data and entertainment services of many kinds. Each subscriber may require a different mix of services, which is likely to change rapidly as connections are established and terminated. Traffic flow may be unidirectional, asymmetrical or symmetrical, again changing with time.

These radio systems compete with other wired and wireless delivery means for the "last mile" connection to services. Use of radio or wireless techniques results in a number of benefits, including rapid deployment and relatively low "up-front" costs.

2.1 Coexistence between systems

IEEE, through the 802.16.1, project is standardizing the air interface (Physical and MAC layers) of a BWA system. However, the allocation of spectrum is not uniquely associated with 802.16.1 systems and so other multipoint solutions are likely to share the various frequency bands set aside for these types of service. Thus, arrangements for satisfactory coexistence of like and unlike systems are required, meaning that the mutual interference between them is low enough to have an acceptably small effect on performance. This is particularly important when multiple systems having different characteristics operate across BTA boundries or across country borders.

Coexistence between the various like and unlike systems is a complex subject, requiring careful analysis on a case-by-case basis. Terrain effects are highly variable between system implementations. Fading due to rain and other atmospheric effects has to be taken into account. Statistical methods may be used to predict the probability that a certain level of interference will be exceeded. Despite these complexities, a number of recommendations and guidelines can be developed to assist planners to achieve acceptable levels of inter-system interference and make good use of the available spectrum. Such recommendations and guidelines are provided in this document.

The two main coexistence cases are:

a. Where two systems operate on the same radio frequency, but are deployed in adjacent geographic areas.

b. Where two systems are deployed in overlapping geographic areas, but operate on adjacent frequencies.

2.2 Reference Diagram

Broadband Wireless Access systems typically include Base Transmitter Stations (BTS) or hubs, Subscriber Transmitter Stations (STS), subscriber terminals equipment, core network equipment, intercell links, repeaters and possibly other equipment. A reference BWA system diagram is provided in Figure 2-1. This diagram indicates the relationship between various pieces of the system. BWA systems may be much simpler and contain only some elements of the network shown in Figure 2-1. As a minimum, a BWA cell will contain one hub or BTS and many STS units. In the figure, the wireless links are shown as broken lines connecting system elements. Antennas with varied radiation patterns may be employed. In general, the subscriber stations utilize a highly directional antenna. Optional repeaters may be used to fill in coverage when a direct RF Line-of-Sight path cannot be established between a subscriber and a BTS. Intercell links

are optional and may be used to interconnect two or more BTS units using wireless techniques. The boundary of the BWA network is at the interface points F and G. The F I interfaces are generally standardized, being points of connection to core networks. The G interfaces, between terminal stations and terminal equipment may be either standardized or proprietary.

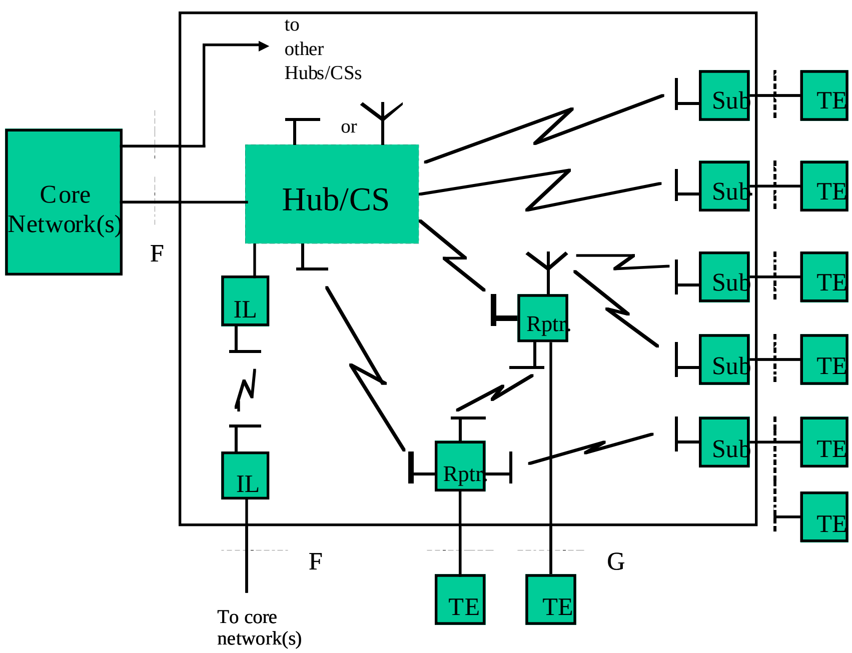


Figure 2-1. Reference Diagram

Key to reference diagram

Hub/CS : The hub of a PMP system, or Central Station (access point) of a MP-MP system A Hub/CS may, optionally, be divided into two parts – control/ interface part and radio part. One control part could support one or a number of radio parts. The interface between the parts is not standardized.

Sub: The Subscriber (Terminal) Station

TE: The Terminal Equipment (a Sub could be connected to more than one TE, dependent on the services required at the user's premises). The TE/Sub interface could be standardized (e.g. telephone interface) or proprietary.

Rptr: A Repeater Station, with optional connection to local terminal equipment.

IL: An Inband (Intercell) Link. Note that an inband link could be used to connect a remote hub to a convenient access point of a core network or, alternatively, could provide a connection between two hubs.

Directional antenna

Omni-directional or sectored antenna

2.3 System Architecture

BWA systems often employ multipoint architectures. The term multipoint includes Point to Multipoint (PMP) and Multipoint-to-Multipoint (MP-MP). The 802.16.1 project will define a PMP system with hub stations and end user stations communicating over a fully specified air interface. A similar PMP standard is in preparation in Europe, in ETSI Project BRAN, which is producing an interoperability standard titled "Hiperaccess". Coexistence specifications for this project are being prepared by the ETSI TM4 committee. In addition, there are a number of proprietary BWA systems, for which the air interface is not standardized.

2.3.1 PMP Systems

PMP systems comprise hub stations, terminal stations and, in some cases, repeaters. Hub stations have relatively wide beam antennas, divided into one or several sectors to provide 360 degree coverage. To achieve complete coverage of an area, more than one hub station may be required. The connection between hubs is not part of the BWA network itself, being achieved by use of radio links, fiber optic cable or equivalent means. Links between hubs may sometimes use part of the same frequency allocation as the BWA itself. Routing to the appropriate hub is a function of the core network. Terminal stations use directional antennas, facing a hub and sharing use of the radio channel. This may be achieved by various access methods, including frequency division, time division or code division.

2.3.2 MP-MP Systems

Multipoint-to-multipoint (MP-MP) systems have the same functionality as PMP systems. Hub stations are replaced by central stations (access points), which provide connections to core networks on one side and radio connection to other stations on the other. A subscriber stations may be a radio terminal or (more typically) a repeater with local traffic access. Traffic may pass via one or more repeaters to reach a subscriber. Antennas are generally narrow beam directional types. By providing means for remote alignment of antennas and suitable network configuration tools, it is possible to achieve high levels of coverage and spectrum efficiency.

2.3.3 Repeaters

Some systems deploy repeaters. In a PMP system, repeaters are generally used to improve coverage to locations where the hub(s) have no line of sight within their normal coverage area(s), or alternatively to extend coverage of a particular hub beyond its normal range. A repeater relays information from a hub to one or a group of subscribers. It may also provide a connection for a local subscriber. A repeater may operate on – frequency (i.e. using the same frequencies as those facing the hub) or it may use different frequencies (i.e., demodulate and remodulate the traffic on different channels). In MP-MP systems, most stations are repeaters, which also provide connections for local subscribers.

2.4 Medium Overview

Electromagnetic propagation over Frequency Ranges 1 through 3 is characteristic of a relatively non-dispersive medium which is dominated by increasingly severe rain attenuation as frequency increases. Absorption of emissions by terrain and man-made structures is severe, leading to the normal requirement for optical line-of-sight between transmit and receive antennas for satisfactory performance. Radio systems in this frequency regime are typically thermal or interference noise-limited (as opposed to multipath-limited) and have operational ranges of a few kilometers due to the large free-space loss and the sizable link margin which has to be reserved for rain loss. At the same time, the desire to deliver sizable amounts of capacity promotes the use of higher-order modulation schemes with the attendant need for large C/I for satisfactory operation. Consequently, the radio systems are vulnerable to interference from emissions well beyond their operational range. This is compounded by the fact that the rain cells which produce the most severe rain losses are not uniformly distributed over the operational area thus creating the potential for scenarios where the desired signal is severely attenuated but the interfering signal is not.

3 Equipment Design Parameters

This section provides recommendations for important equipment design parameters which significantly affect interference levels and hence coexistence. Recommendations are made for the following BWA equipment: base station equipment, subscriber equipment, repeaters and intercell links (including PTP equipment). Recommendations are for both transmitter and receiver portions of the equipment design. The recommended limits are applicable over the full range of enviromental conditions for which the equipment is designed to operate including temperature, humidity, input voltage, etc.

3.1 Transmitter Design Parameters

This section provides recommendations for the design of both subscriber and base station transmitters which are to be deployed in Broadband Wireless Access systems. Recommendation are also made for repeaters and intercell links.

3.1.1 Maximum EIRP Spectral Density

The amount of interference within a given area is often specified in terms of *power flux density*. This parameter is expressed in terms of Watts/square meter. However, because point-to-multipoint systems span very broad frequency bands and utilize many different channel bandwidths, a better measure of interference is *power spectral flux density* rather than power flux density. Since interference within a given area is directly related to the excitance from various transmitters, it is important to have some upper limits on transmitted power. Or more accurately, limits for the equivalent isotropically radiated power spectral density. The following paragraphs recommend EIRP power spectral density limits. These limits apply to the mean EIRP spectral density produced over any continuous burst of transmission. The spectral density should be assessed with an integration bandwidth of not more than 1 MHz; i.e. these limits apply over any 1 MHz bandwidth.

3.1.1.1 Base Station: Frequency Range 2 (23.5 – 43.5 GHz)

BWA base stations or hubs conforming to the recommendations of this practice should not produce an EIRP power spectral density exceeding 14 dBW/MHz. This limit applies to the mean EIRP spectral density produced over any continuous burst of transmission. (Any pulsed transmission duty factor does not apply.) The spectral density should be assessed with an integration bandwidth of not more than 1 MHz; i.e. these limits apply over any 1 MHz bandwidth. . Note for the specific sub band 25.25-27.5 GHz, the limits set out in ITU-R Document 7D-9D/TEMP/XX should be used, which are specified as follows:

the e.i.r.p. spectral density of the emission in the direction of any geostationary orbital (GSO) location specified in Recommendation ITU-R SA.1276 should not exceed the following values in any 1 MHz band for the elevation angle θ above the local horizontal plane

+8 dBW for $0° \le \theta \le 20°$

+14 – 10 log(θ/5) dBW for $20° < \theta \le 90°$

In any other azimuthal direction, the e.i.r.p. spectral density of the emission should not exceed the following values in any 1 MHz band for the elevation angle θ above the local horizontal plane:

+14 dBW for $0° \le \theta \le 5°$

+14 – 10 log(θ /5) dBW for $5° < \theta \le 90°$

Refer to ITU-R document for further details.

3.1.1.2 Subscriber: Frequency Range 2 (23.5 –43.5 GHz)

BWA subscriber stations conforming to the recommendations of this practice should not produce an EIRP spectral density exceeding 30 dBW/MHz. This limit applies to the mean EIRP spectral density produced over any continuous burst of transmission. (Any pulsed transmission duty factor does not apply.) The spectral density should be assessed with an integration bandwidth of not more than 1 MHz; i.e. these limits apply over any 1 MHz bandwidth. Note, the 30 dBW/MHz limit applies to the CPE operating under faded conditions (rain attenuation). A lower limit is specified for unfaded conditions, as described in 3.1.2. . Note for the specific subband 25.25-25.75 GHz, the recommended subscriber EIRP limits , as defined by ITU-R Temp document XX, are as follows:

3.1.1.3 Repeater Stations: Frequency Range 2

There are several possible types of repeater. The first type is used in a PMP system to reach subscribers within the nominal radius of a hub for which no direct line of sight is possible. These may operate on – frequency or use different frequencies from those used by the hub (demodulating and remodulating repeater). EIRP limits in this recommended practice are the same for both types [NOTE: THIS RECOMMENDATION IS SUBJECT TO FURTHER DISCUSSION].

A further type of repeater is used to extend the coverage of a base station beyond its nominal radius. From the point of view of EIRP limits, such repeaters are regarded as behaving in the same way as hubs. Repeaters may also be employed to facilitate the transmission of signals from the subscriber station to the base station; in this case, they behave similar to subscriber units. Other configurations for repeaters are possible.

Four different limits should apply, according to the system configuration and direction faced by the repeater (i.e. whether the hub – facing direction or subscriber facing direction is specified).

3.1.1.3.1 Repeaters (direction facing hub): 30 dBW/MHz

BWA repeater stations in PMP systems in the direction facing a hub, using directional antennas and conforming to the equipment requirements of this practice should not produce an EIRP spectral density exceeding 30dBW/ MHz. These limits apply to the mean EIRP spectral density produced over any continuous burst of transmission (Any pulsed transmission duty factor does not apply). The spectral density should be assessed with an integration bandwidth of not more than 1MHz; i.e. these limits apply over any 1MHz bandwidth.

3.1.1.3.2 Repeaters (direction facing multiple subscribers): 14 dBW/MHz

BWA repeater stations in PMP stations the direction facing subscribers, using sectored antennas and conforming to the equipment requirements of this practice should not produce an EIRP spectral density exceeding 14dBW/ MHz. These limits apply to the mean EIRP spectral density produced over any continuous burst of transmission (Any pulsed transmission duty factor does not apply). The same limit should apply to all kinds of repeater, whether operating on – frequency or not. The spectral density should be assessed with an integration bandwidth of not more than 1MHz; i.e. these limits apply over any 1MHz bandwidth.

3.1.1.4 Inband Intercell Links: Frequency Range 2

Inband Intercell Links (ICLs) are point to point (PTP) radios operating within Frequency Range 2 when used. They provide a wireless backhaul capability between base stations at rates ranging from DS-3 to OC-3. The advantage of ICLs is that they can share a common infrastructure as the PMP systems, e.g. the switch, to minimize overall network rollout costs. Additionally, ICL radios can operate under the auspices of the PMP license, thus avoiding the burden of additional licensing and cost associated with out of band PTP systems.

ICL radios typically employ high gain antennas to facilitate ranges that are at least twice the radius of a typical LMDS/CS PMP system, e.g. 8-10 km. Based on this, the following typical parameters are assumed for a 28 GHz ICL transmitter:

G_{TX} = 42 dBi
P_{TX} = 0 dBW/carrier
Carrier BW = 50 MHz
Modulation = 16 QAM (data rate~150 Mb/s)

Power density = $P_{TX} - 10 \text{ Log } (BW_{MHz}) = 0 - 10\text{Log}(50) = -17$ dBW/MHz

EIRPSD = $P_{TX} + G_{TX} = -17 + 42 = 25$ dBW/MHz.

Allowing for some extra margin, the EIRPSD may be as high as 30 dBW/MHz.

Therefore, ICL radios conforming to the equipment recommendations of this practice should not produce an EIRP spectral density exceeding 30 dBW/MHz. This limit applies to the mean EIRP spectral density produced over any continuous burst of transmission. The spectral density should be assessed with an integration bandwidth of not more than 1 MHz.

3.1.2 Upstream Power Control

BWA subscriber stations conforming to the equipment design parameters recommended by this practice should not transmit an EIRP spectral density of more than 15 dBW/MHz under unfaded conditions, i.e. for clear sky conditions. This requirement is met if the maximum EIRP spectral density produced by the equipment is always less than 15 dBW/MHz, or it may be met by employing adaptive transmit power control to reduce EIRP spectral density below this limit during unfaded conditions, i.e. in clear or no-rain conditions . Note that a CPE can transmit up to a maximum EIRP value of 30 dBW/MHz during faded conditions (i.e. during rain fades) as described in section 3.1.1.2.

3.1.3 Down Stream Power Control

This practice assumes that no downstream power control is employed. However, it is recommended that the minimum power necessary to maintain the link be employed. And in all cases, the recommended limits given in paragraph 3.1.1.1 should be met.

3.1.4 Frequency Tolerance or Stability

The system should operate within a frequency stability of +/- 10 parts per million. [NOTE: This specification is only for the purposes of complying with *coexistence* requirements. The stability requirements contained in the PHY specifications may be more stringent, particularly for the base station. In addition, it is highly recommended that the CPE transmit frequency be controlled by using a signal from the downstream signal(s).]

3.2 Receiver Design Parameters

This section provides recommendations for the design of both subscriber and base station receivers which are to be deployed in Broadband Wireless Access systems. The parameters for which recommendations are made are those which affect performance in the presence of interference from other BWA systems.

3.2.1 Base Station Selectivity and Interference Tolerance

The base station receiver is expected to be subjected to adjacent channel interference and co-channel interference from other BWA systems operating in close proximity to the reference system. Therefore the base station receivers must be designed with proper selectivity and tolerance to interference. The following paragraphs recommend minimum design standards to allow for interference.

3.2.1.1 Co-channel Interference Tolerance

The receiver should be capable of operating at the specified BER in the presence of a co-channel interference signal that is 6 dB below the receiver's noise floor, causing a total noise floor degradation of 1.0 dB. The minimum allowable degradation in the receivers effective noise floor of 1.0 dB was chosen as an acceptable degradation level upon which to operate a BWA system while allowing interference levels to be specified in an acceptable manner.

3.2.1.2 Adjacent Channel Interference Tolerance

The receiver must be capable of operating at the specified BER in the presence of an adjacent channel interference signal that is equal in power to the desired signal, i.e. C/I_{adj} = 0 dB.

3.2.1.3 CW Interference Tolerance

A CW interferer, at a level of +30 dB with respect to the wanted signal and at any frequency up to 60 GHz, excluding frequencies within 500% of the center frequency of the wanted signal, should not cause a degradation of more than 1 dB of the BER threshold.

3.2.2 Subscriber Station Selectivity and Interference Tolerance

The subscriber receiver is expected to be subjected to adjacent channel interference and co-channel interference from other BWA systems operating in the close proximity to the reference system. Therefore

the receivers intended for subscriber terminal applications should be designed with the proper selectivity and tolerance to interference. The following paragraphs recommend minimum design standards to allow for interference.

3.2.2.1 Co-channel Interference Tolerance

The receiver should be capable of operating at the specified BER in the presence of a co-channel interference signal that is 6 dB below the receiver's noise floor, causing a total noise floor degradation of 1.0 dB. The minimum allowable degradation in the receivers effective noise floor of 1.0 dB was chosen as an acceptable degradation level upon which to operate a BWA system while allowing interference levels to be specified in an acceptable manner. (See paragraph 4.4.)

3.2.2.2 Adjacent Channel Interference Tolerance

The receiver should be capable of operating at the specified BER in the presence of an adjacent channel interference signal that is equal in power to the desired signal, i.e. C/I_{adj} = 0 dB.

3.2.2.3 CW Interference Tolerance

A CW interferer, at a level of +30 dB with respect to the wanted signal and at any frequency up to 60 GHz, excluding frequencies within 500% of the center frequency of the wanted signal, should not cause a degradation of more than 1 dB of the BER threshold.

3.3 Unwanted Emissions

Unwanted emissions produced by the operator's equipment and occuring totally within an operator's authorised band are only relevent for that operator. Unwanted emissions from an operator into adjacent bands must be constrained to avoid giving unacceptable interferrence to users of adjacent spectrum.

Some transmitters may be frequency agile to cover several authorized bands and may deploy a band edge RF filter only at the extremities. The possibility of Spectrum Segregation implies that operator segregation edge frequencies may occur within an authorized band. Thus unwanted emissions at authorized band edges or at segregation band edges well inside the agility range may not benefit from the band edge RF filter and may be more severe (or "worst-case") compared to emissions at the extremities.

This practice contains some limits which should be applied at the mid band segregation or authorized edge and the equipment performance is assumed to be equivalent or better at the extremity authorised band edges.

To facilitate assessing emissions at a mid-band segregation or authorized band edge, a virtual block edge is defined and testing (the results are assumed to be valid across the complete operational band) should be implemented at this virtual block edge. Unwanted emissions are to be measured at the output of the final amplifier stage or referenced to that point. In additon to active amplifiers, the final amplifier ***stage*** may contain filters, isolators, diplexers, OMT, etc. as needed to meet emission requirements.

Single-carrier and multi-carrier requirements are described below. If multicarrier operations are intended, then both requirements must be met. "Multicarrier" refers to multiple independent signals (QAM, QPSK, …) and does NOT refer to techniques such as OFDM.

Single carrier and multi-carrier tests are to be carried out relative to a virtual block edge (defined in the Table 3-1). The virtual block edge is located within the assigned band (see Figure 3-1 below). When a transmitter is designed to only operate in part of a band (e.g. because of Frequency Division Duplexing), the virtual block edge should be inside the designed band of operation. The occupied bandwidth of the carrier(s) must be closer to the center of the block than the virtual block edge. The virtual block edge is only to be used for testing and does not impact an actual implementation in any way. One virtual block edge (at frequency f_{vl}) should be inside the lower edge of the designed or assigned band and the other virtual block edge (at frequency f_{vu}) should be inside the upper edge of the designed or assigned band.

Band	Minimum Separation between Actual and Virtual Block Edge
24/26 GHz	10 MHz
28 GHz	40 MHz
38 GHz	10 MHz

Table 3-1. Minimum Separation between Actual and Virtual Band Edge for Different Bands

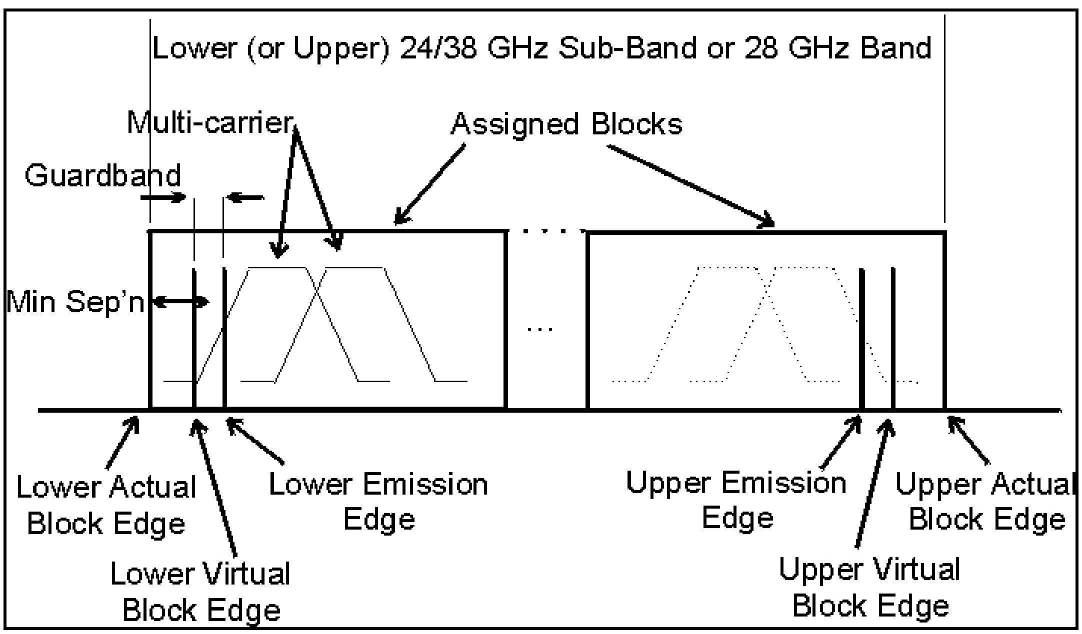


Figure 3-1. Band Edge Definitions

3.3.1 Unwanted Emission Limit

Unwanted emissions spectral density should be attenuated by at least A (dB) below the total mean output power P_{mean} as follows:

(1) For a single carrier transmitter (see section A.1.1) :

In any 1.0 MHz reference bandwidth, outside the virtual block edge, and removed from the virtual block edge frequency by up to and including ±200% of the occupied bandwidth (i.e. 2 B_o): at least A = 11 + 40 f_{offset}/B_o + 10 $\log_{10}(B_o)$, dB, where B_o is in MHz and f_{offset} = frequency offset (in

MHz) from the virtual block edge. Attenuation greater than 56 + 10 $\log_{10}$ (B_o) dB, or to an absolute level lower than -43 dBW/MHz, is not required. For emissions in which the occupied bandwidth is less than 1 MHz, the required attenuation is to be calculated using A= 11 + 40 f_{offset}/B_o dB. Guard bands, if used in the equipment design, must also be used in testing the spectrum mask.

(2) For a multi-carrier transmitter or multi-transmitters (not OFDM) into a common final stage amplifier (see section A.1.2):

The mask is to be the same as in (1), using the *occupied* bandwidth that is defined for multi-carrier transmitters in section 1.3. The total mean power is to be the sum of the individual carrier/transmitter powers. Guard bands, if used in the equipment design, must also be used in testing the spectrum mask.

Note: Several transmitters into a common non-active antenna cannot use the multi-carrier mask for the composite signal. In this case the appropriate mask applies to the individual transmitter.

(3) In any 1.0 MHz band which is removed from the identified edge frequency by more than $\pm$200% of the occupied bandwidth:

At least 43 + 10 $\log_{10}$ (P_{mean}) dB (i.e. –43 dBW), or 80 dB below P_{mean}, whichever is less stringent. P_{mean} is the mean output power of the transmitter (or, in the case of multi-carriers/multi-transmitters, the sum of the individual carrier/transmitter powers) in watts.

3.4 Antenna

Antenna design challenges vary from one frequency range to another. While achieving a certain level of performance for any given parameter might be easy at lower frequencies, it often proves to be difficult at higher frequencies or vice versa. Also, the number of coexisting systems varies from one frequency band to another. The amount of interference pollution, therefore, varies across the broad frequency range of interest of 802.16. Having said the above, in order to come up with antenna requirements for a more or less homogeneous environment, three frequency ranges are defined.

- Range 1: 10 GHz To 23.5 GHz
- Range 2: 23.5 GHz To 43.5 GHz
- Range 3: 43.5 GHz To 66 GHz

Most of the BWA systems operate within the Range 2. Therefore, Range 2 is the focus of this document.

3.4.1 Antenna Classes

Various classes of antennas may be defined. The performance of the antenna can be divided into three classes. Depending on the performance and the type of environment the antennas will be operating in, antennas are divided into electrical and mechanical classes. These classes help service providers in the selection of antennas that are just right for the deployment environment without the excess cost of unnecessary high-performance antennas if the interference environment is a benign one.

In each of the three frequency ranges mentioned above, antennas are divided into three classes with respect to electrical performance. The main factor distinguishing among classes is the level and severity of interference in the environment. It should be noted here that the final decision on the selection of an antenna class is for the service provider to make. The following are only recommended guidelines.

3.4.1.1 Electrical Class 1

Class 1 antennas are meant for operation in environments in which interference levels are insignificant. This could be due to many factors including

- absence of coexisting systems in the same geographical area
- conservative reuse creating a benign self-interference environment
- coexisting systems being far enough such that the power spectral density flux density resulting from those systems is negligible

In such conditions, less complicated, low-cost antennas with minimum requirements specified in this document could be deployed.

3.4.1.2 Electrical Class 2

Class 2 antennas are meant for operation in environments in which interference levels could be potentially significant and cause problems under certain conditions. Factors contributing to the interference being upgraded from insignificance (in case of class 1) to potentially significant (in case of class 2) are

- Existence of at least one coexisting system in the same geographical area
- A reuse pattern which may cause self-interference problems in certain areas
- Proximity of coexisting systems such that the interferer's' power spectral density flux density is not negligible.

In such conditions, antennas with higher levels of discrimination in side lobes and back lobes need to be deployed to guarantee the acceptable performance of the system.

3.4.1.3 Electrical Class 3

Class 3 antennas are meant for operation in environments in which interference levels are highly significant. Factors contributing to highly significant interference are

- Existence of several coexisting systems in the same geographical area
- Aggressive reuse pattern which creates significant self-interference levels throughout the network
- Extreme proximity to a coexisting system, e.g. adjacent cells.

In such conditions, highly efficient antennas with optimum pattern and very low side lobes and high front-to-back ratio need to be deployed to guarantee the performance of the system.

3.4.1.4 Mechanical Classes

In order to capture the environmental effects on antennas and their performance while operating within a BWA network, two mechanical classes are proposed. These two classes are heavy duty and normal duty. The use of high-directivity, pencil-beam subscriber antennas at rooftops creates a unique situation in regard to vibrations and lateral movements of the antenna structure due to wind. Half a degree deviation from the orientation set by network planners could potentially lead to several dB losses in signal strength. However, while hurricane-prone areas require heavy-duty antenna systems, other areas could benefit from cheaper, normal-duty antennas.

3.4.2 Antenna Parameters

The following antenna parameters affecting the coexistence of BWA systems apply to both BTS and STS antennas.

3.4.2.1 Polarization

Rain attenuation is the dominant impairment in the frequency range of our focus; namely, range 2. Due to insignificant depolarizing effect of rain on vertical or horizontal polarization, only these two polarization states are considered for operation in BWA systems. The required polarization purity is captured in the specification of antenna XPD in the next section. Also, the AZ and EL RPEs should be identical for vertically and horizontally polarized antennas.

3.4.2.2 VSWR

Voltage Standing Wave Ratio (VSWR) does not directly affect the coexistence of BWA systems. If not kept at a minimum level throughout the operation bandwidth, however, it reduces the radiated power out of the antenna below planned limits. A reduced carrier power leads to smaller C/(I+N). A VSWR of 1.9 is equivalent to about 10% loss of power due to reflection. Therefore, it is recommended that the VSWR of the BWA antenna be kept below 1.9 across the entire target spectrum with 1.5 being the typical value (4% loss of power due to reflection).

3.4.2.3 Passive Intermodulation (PIM)

Passive Intermodulation (PIM) directly affects coexistence of BWA systems. PIM could be generated in both transmitting and receiving antenna. When combined with other forms of coexistence-related interference, the additional noise added to the noise floor of the receiver due to passive intermodulation products could potentially affect the operation of a BWA system. It is recommended that the BWA antennas perform at 100 dBc or better in regards to passive intermodulation.

3.4.3 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.

3.4.3.1 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. 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 should 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 should 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 should be specified as required to best specify coexistence principles.

3.4.3.1.1 Linear Polarization

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

3.4.3.1.1.1 Effect on Radiation Pattern Envelope (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 should be identical for horizontal and vertical polarized antennas.

3.4.3.1.1.2 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. The polarization discrimination is specified in the tables governing each class.

3.4.3.1.1.3 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. It is recommended that the cross-polar isolation of a dual polarized antenna should be agreed upon between the equipment supplier and the purchaser in line with the overall system design requirements. The actual value of XPI should be the same as the value of XPD, defined in section 5.1.1.2.

3.4.3.1.1.4 Inter-Port Isolation

Specification of a inter-port isolation for the BTS antenna implies that the antenna is a dual polarized antenna. It is recommended that the inter-port isolation of a 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 30 dB is typical.

3.4.3.1.1.5 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 90º and less should be minimally 60 dB.

3.4.3.1.2 Radiation Pattern Envelop (RPE)

3.4.3.1.2.1 Azimuth Radiation Pattern Envelopes, Sectored

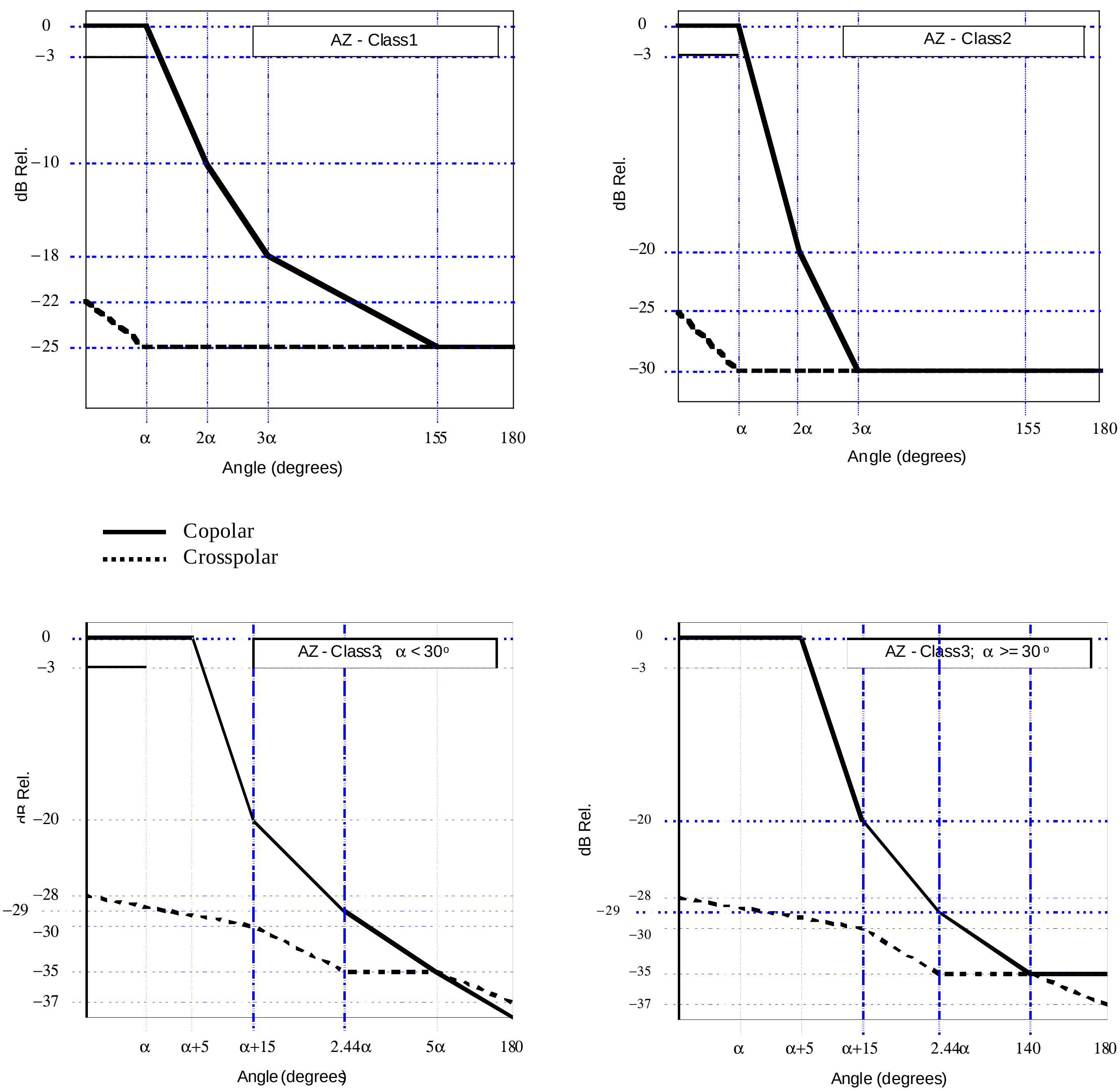
The azimuth radiation pattern envelope is specified in terms a variable α that is _ the 3 dB beamwidth of the antenna. Sector sizes for these RPE tables range from 15^o to 135^o. A 180^o sector will be considered a special case for use in generation of an omni-directional antenna pattern.

3.4.3.1.2.2 Azimuth RPE

A Class 1 implementation involves a low interference environment, and as such requires the use of a *standard* performance antenna. A Class 2 implementation involves a moderate to high interference environment, and as such requires the use of a *high performance* antenna. A Class 3 implementation involves a very high interference environment, and as such requires the use of an *ultra high performance* antenna.

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

Class 1: Copolar and Crosspolar **Class 2: Copolar and Crosspolar**



3.4.3.1.2.3 Elevation Radiation Pattern Envelopes, Sectored

3.4.3.1.2.3.1 Coexistence Issues

The elevation pattern should be specified both above and below the horizon, to provide isolation, improve coexistence, and to ensure efficient use of radiated power.

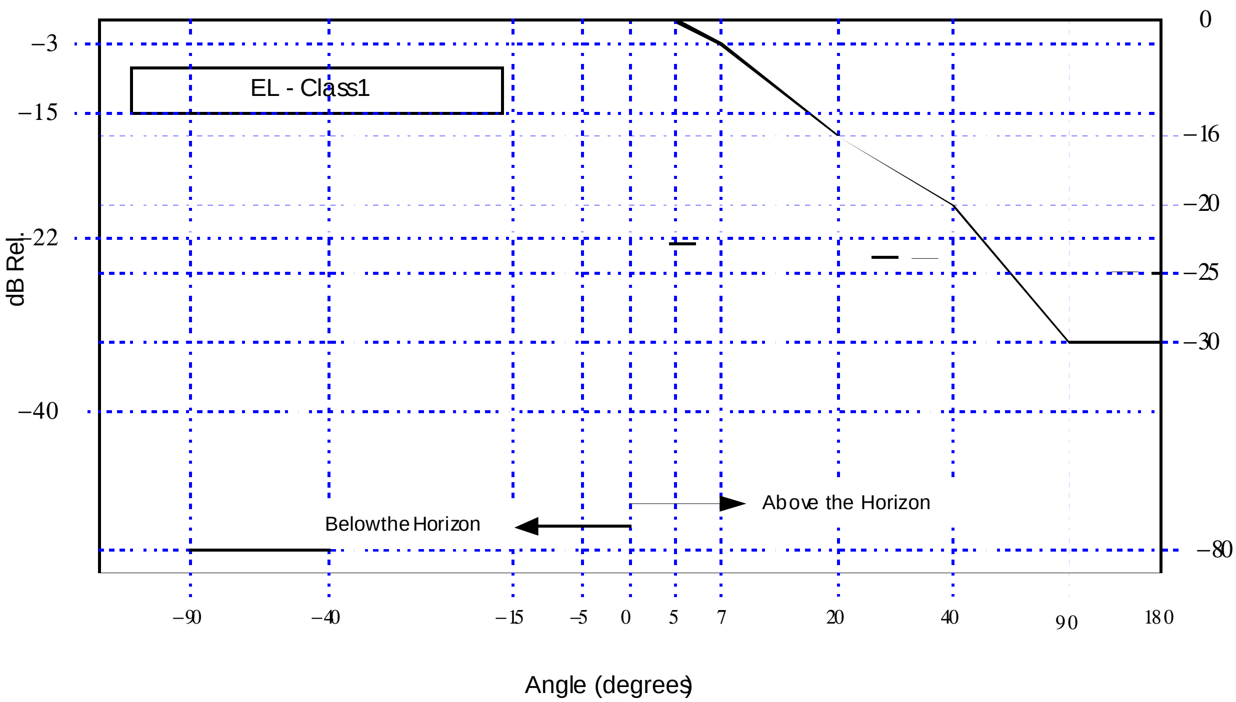
3.4.3.1.2.3.2 Reference Directions

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

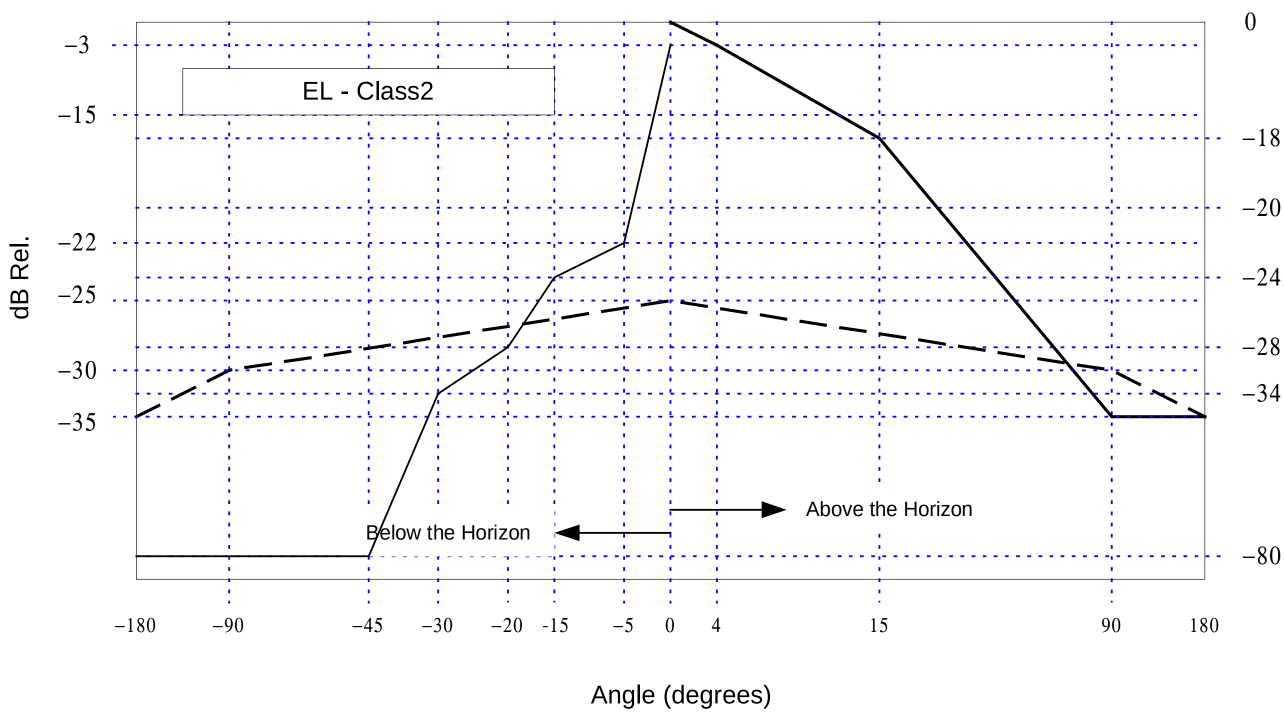
It may be necessary in practical deployments to use electrical or mechanical tilt, or a combination of both, to achieve the required cell coverage, taking into account the surrounding terrain, for example.

The elevation pattern is considered appropriate for the commonly used range of 0 to –10 degrees of downtilt. A further downtilt of up to ± 10 degrees may be suitable for some situations. A tilt is translated onto the corresponding patterns as an angular shift along the elevation angle axis.

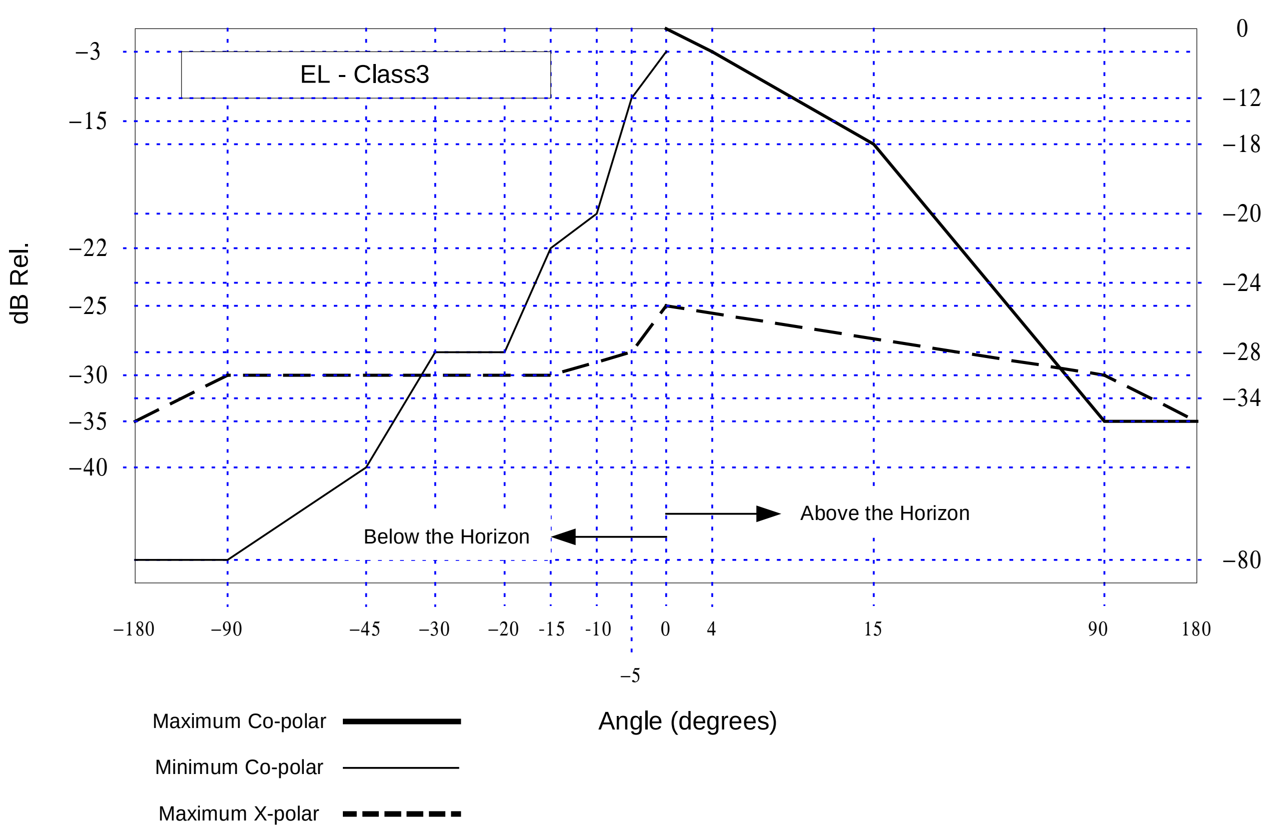
3.4.3.1.2.3.3 Class-1 Elevation RPE.



3.4.3.1.2.3.4 Class-2 Elevation RPE.



3.4.3.1.2.3.5 Class-3 Elevation RPE



3.4.3.1.2.2 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° sector antennas in a back-to-back configuration. It should be noted that when two 180° 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.

3.4.3.1.3 Minimum Boresight Gain

The BTS sector antenna should be designed for maximum efficiency, and lowest possible levels of extraneous radiation which might result in unacceptable levels of interference. The following Table is provided as a guideline, for minimum antenna gain as a function of sector size.

The minimum gain should be agreed upon between the equipment supplier and purchaser in line with the overall system design requirements.

Sector Angle (deg)	Recommended Boresight Minimum Gain (dBi)
15	
30	
45	16
60	
90	13
135	
180	10

3.4.3.2 Mechanical Characteristics

3.4.3.1.3 Wind and Ice Loading

Wind loading as specified in this document for the BTS results in mechanical deformation or misalignment that would cause the radiated pattern to be altered and, hence, affect the coexistence characteristics. Antennas should meet the system operational requirements while subjected to the expected wind and ice loading in the geographical installation area. The angular deviation of the antenna main beam axis during specified operational conditions should not be more than 0.5 degrees. The antenna can exceed this deviation during survival conditions, but should return to its original pointing direction after the survival condition ceases. In any case, the minimum design operational wind load should be 70 mph, and the minimum design survival wind load should be 100mph. These minimum specified loads may be increased substantially in many geographical areas. If potential ice buildup is a factor, the ice thickness should be considered radial with the density assumed to be 44lb/ft^3. Consideration of ice buildup on the radome face depends on the material of the radome and whether a heater is utilized. Radome ice should be considered on a case by case basis.

3.4.3.1.4 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.

3.4.3.1.5 Temperature and Humidity

The antennas must not suffer performance degradation when subjected to temperature or humidity extremes, which could potentially cause interference. As a guideline, antennas should be designed to operate within a temperature range of –40°C to +40°C, with relative humidity from 1 to 100%.

3.4.3.2 Miscellaneous Additional Elements

3.4.3.2.1 Radomes

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

3.4.3.2.2 Heaters

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

3.4.3.2.3 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.

3.4.3.2.4 Mechanical Adjustment Assembly

The sector antennas described in this specification typically have a wide azimuth pattern and a narrow elevation pattern. The mechanical tilting assembly should accommodate adjustments in elevation and azimuth, consistent with the overall system design requirements .

3.4.4 Subscriber Station Antenna

STS antennas are highly directional, narrow-beam antennas. The specification defines three directivity categories for STS antennas; category one through three. While category two antennas could be used for normal operation, category 3 could be used for achieving greater range or better availability.

3.4.4.1 Minimum Cross-Polar Discrimination (XPD)

The STS antennas should follow the same guidelines set for BTS antennas in regards to XPD unless other wise specified by the relevant RPEs.

3.4.4.2 Minimum Cross-Polar Isolation (XPI)

The STS antennas should follow the same guidelines set for BTS antennas in regards to XPI.

3.4.4.3 Inter-Port Isolation

The STS antennas should follow the same guidelines set for BTS antennas in regards to inter-port isolation.

3.4.4.4 Directivity Categories

Two directivity categories are recommended for STS antennas: category 2 and category 3. While category one should be used under special circumstances, category 2 is recommended for use under normal conditions. Category 3 antenna should be used a) to provide additional gain in the link budget for providing coverage to certain Subscriber Stations, and b) to control the level of interference given the smaller beamwidth of such antennas.

STS antennas should provide a maximum co-polar directivity in the ranges specified below.

- Directivity category 1: 26 to 34 dBi
- Directivity category 2: 34 to 42 dBi
- Directivity category 3: 42 to 48 dBi

The maximum cross-polar directivity should follow the minimum XPD guidelines as stated in this document.

3.4.4.5 Radiation Pattern Envelop (RPE)

The following tables show the RPEs of co- and cross-polar patterns for directivity categories 2 and 3. The required side lobe level and front-to-back ratio of the STS antenna depends on the coexistence scenario, C/I requirements of the radios, rain region, and the pattern of BTS antenna. It is recommended here that all of the above-mentioned parameters be taken into consideration in choosing the right class of antenna.

In the following graphs, α is one half of the half-power beamwidth of the antenna. It is also assumed that the same RPE should apply to both E- and H-plane. There is, however, no requirement on the symmetry of the antenna patterns as long as they meet the following RPEs. Please refer to Appendix C for a tabular listing of RPEs.

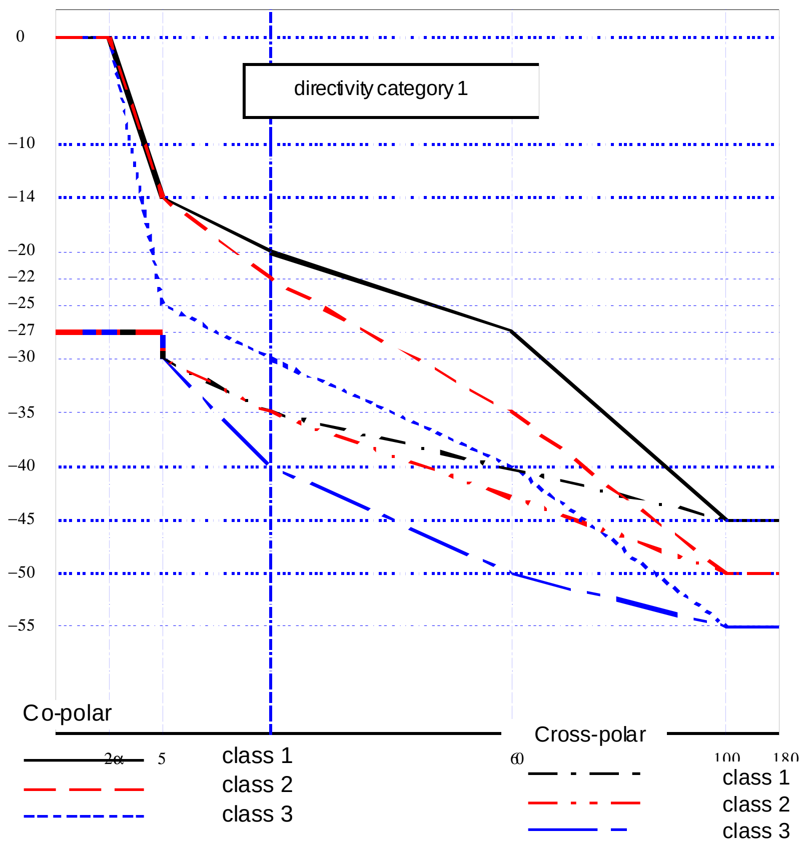


Figure 3-2. Category 1 Antenna Directivity

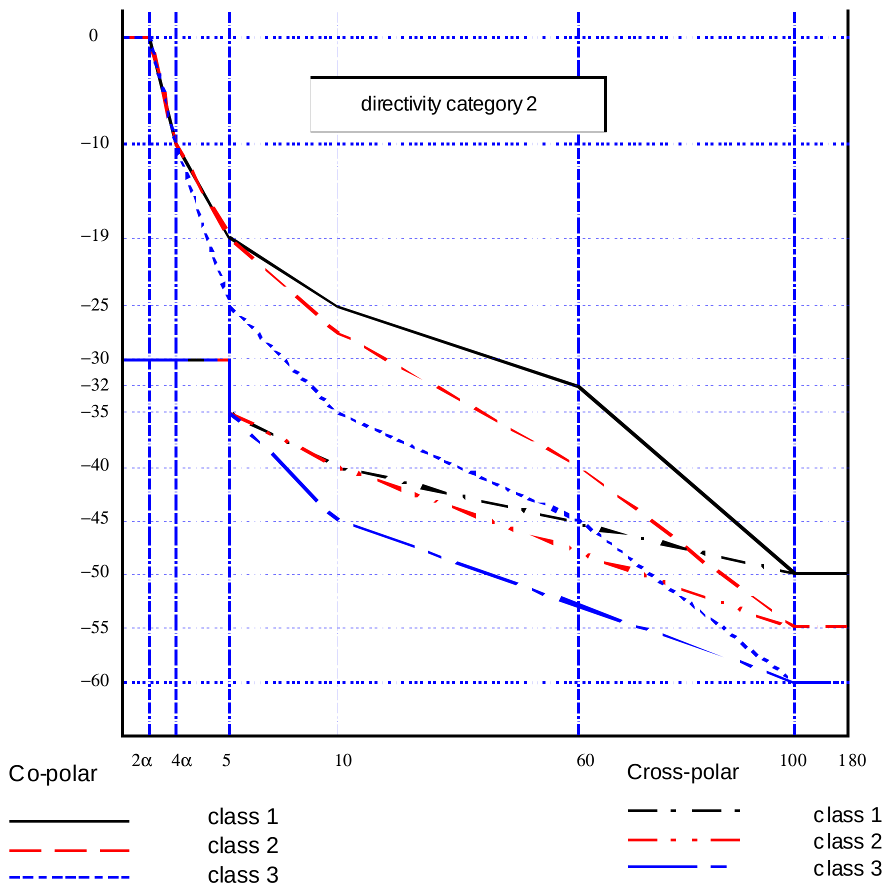


Figure 3-3. Category 2 Antenna Directivity

3.4.4.6 Mechanical Characteristics

The following mechanical characteristics of STS antennas, directly or indirectly, affect the coexistence of BWA systems.

3.4.4.6.1 Vibration

Due to narrow azimuth and elevation beamwidth, the STS antennas should be highly stable and undergo little mechanical deformation due to wind and other sources of vibrations. It is recommended that the maximum deviation of the antenna main beam axis due to any reason should be kept less than or equal to half of the beamwidth of the antenna over the designed environmental conditions.

3.5 Other

3.5.3 EMI/EMC Parameters (Leland)

4 System Design

4.4 Receiver Sensitivity Degradation Tolerance

Receiver sensitivity determines the minimum detectable signal and is a key factor in any link design. However, as the level of receiver noise floor increases, the sensitivity degrades. This, in turn, causes reduction in cell coverage, degradation in link availability, and loss of revenues. The factors contributing to the increase in noise power divide into two groups, internal and external. The Internal factors include, but are not limited to, the noise generated by various components within the receiver, intermodulation noise, and intra-network co- and adjacent-channel interference. The external factor is caused by inter-network interference due to coexistence.

The amount of degradation in receiver sensitivity is directly proportional to the total noise power added to the thermal noise, ΣI, consisting of intra- and inter-network (coexistence) components.

$$\Sigma I = P_{\text{intra}} + P_{\text{coex.}}$$

In order to reduce the contribution of coexistence in ΣI, it is recommended that the effect of any BWA network on any other coexisting BWA network should not degrade the receiver sensitivity of that BWA network by more than 1 dB. This is the level that triggers the coordination process discribed in section 7.1.

4.5 Subscriber TX lock to prevent transmissions when no received signal present –Erol

In the absence of a correctly received signal, the subscriber transmitter should be disabled. This is intended to prevent unwanted transmission from creating inference that would prevent normal system operation due to antenna mis-alignment. The subscriber should continuously monitor the received signal and if a loss of received signal is detected, no further transmissions are allowed until the received signal is restored. If the received signal is lost *while the unit is transmitting* the unit is permitted to complete the current transmission. This gives the subscriber a mechanism to notify the basestation of the system fault.

4.6 Fail-safe

It is recommended that the subscriber and base station equipment have the ability to detect and react to failures, either software or hardware, in a manner to prevent unwanted emissions and interference. The following is an example list of items the equipment should monitor:

- TX PLL lock status
- Power Amplifier drain voltage/current
- Main power supply
- Microprocessor watchdog

The implementation of which items to monitor and preventive and/or corrective actions are considered to be vendor specific and not intended to increase system cost. However, the intent is to prevent transmissions which may result in system interferrence due to individual CPE failures.

5 Interference and Propagation Evaluation

5.4 Develop Interference Scenarios [TBD]
5.5 Description of model and simulation to evaluate interference [TBD]
5.6 Results of modeling and simulation for example scenarios [TBD]

6. Frequency Plans

6.1 Band Plans [resolution needed]

This document addresses coexistence issues in multiple bands. The following paragraphs provide instantiations for some of these bands.

6.1.1 US 28 GHz Band Plan

The following reference band plan will be used for coexistence for FDD systems using the US LMDS band.

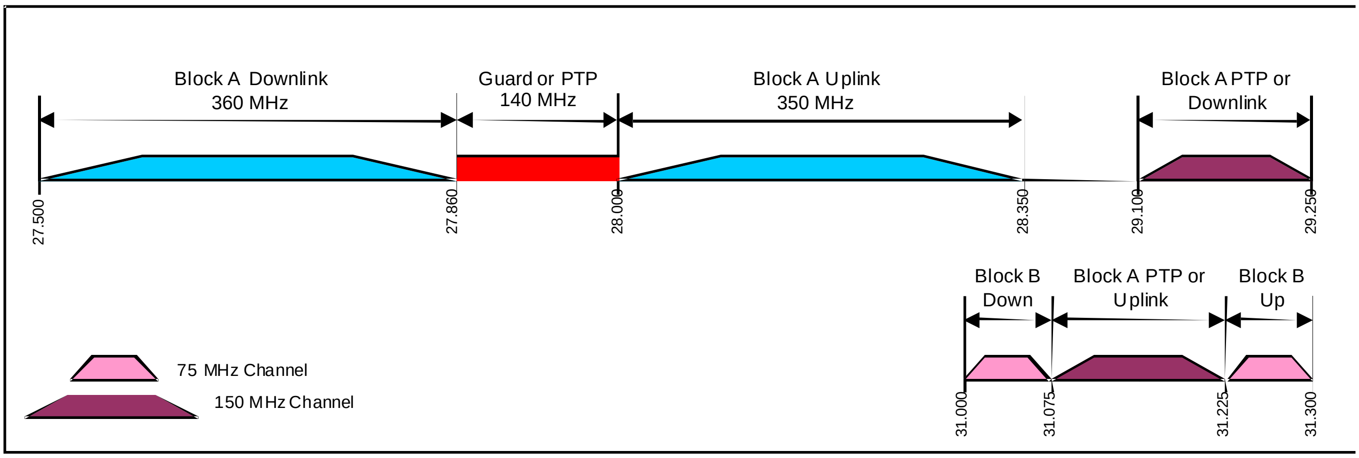


Figure 6-1. Proposed Reference Bandplan for FDD systems within the U.S. LMDS band.

i. Within the 27.5 to 28.35 GHz band, no FDD downstream transmitters will radiate more than –30 dBm/MHz power above 27.925 GHz and no upstream FDD transmitters will radiate more than -30 dBm/MHz power below 27.925 GHz.

ii. Within the 27.5 – 28.35 GHz band, the power input to an FDD BST will be less than or equal to – 40 dBm/MHz above 27.925 GHz.

iii. Within the 27.5 – 28.35 GHz band, the power input to an FDD CPE will be less than or equal to – 70 dBm/MHz below 27.925 GHz.

iv. Within the 27.5 to 28.35 GHz band, no FDD system BTS will transmit on frequencies greater than 27.925 GHz..

v. Within the 27.5 to 28.35 GHz band, no FDD system CPE will transmit on frequencies below 27.925 GHz.

vi. For FDD systems, Block B downstream is 31.0 to 31.075 GHz and upstream is 31.225 to 31.3 GHz for BST to CPE systems.

vii. TDD PMP systems may operate in any band not specifically reserved for PTP use.

6.1.2 Canadian Band Plan for the 24 GHz

The following reference band plan will be used for coexistence for the 24 GHz band:

Block	Lower block (MHz)	Upper block (MHz)
A/A’	24250-24290	25050-25090
B/B’	24290-24330	25090-25130
C/C’	24330-24370	25130-25170
D/D’	24370-24410	25170-25210
E/E’	24410-24450	25210-25250

Frequency division duplex (FDD) systems: the base to subscriber links are preferred in the lower frequency blocks; the subscriber to base links are preferred in the upper frequency blocks.

Time division duplex (TDD) systems: may operate in both the lower and upper sub-bands.

6.1.3 Canadian Band Plan for the 38 GHz [add us and others—leland]

The following reference band plan will be used for coexistence for the 38 GHz band:

Block	Lower Block (MHz)	Upper Block (MHz)	Usage
A/A’	38600 – 38650	39300 – 39350	P-P
B/B’	38650 – 38700	39350 – 39400	P-P
C/C’	38700 – 38750	39400 – 39450	P-P, P-MP
D/D’	38750 – 38800	39450 – 39500	P-P, P-MP
E/E’	38800 – 38850	39500 – 39550	P-P, P-MP
F/F’	38850 – 38900	39550 – 39600	P-P, P-MP
G/G’	38900 – 38950	39600 – 39650	P-P, P-MP
H/H’	38950 – 39000	39650 – 39700	P-P, P-MP
I/I’	39000 – 39050	39700 – 39750	P-P, P-MP
J/J’	39050 – 39100	39750 – 39800	P-P, P-MP
K/K’	39100 – 39150	39800 – 39850	P-P
L/L’	39150 – 39200	39850 – 39900	P-P
M/M’	39200 – 39250	39900 – 39950	P-P
N/N’	39250 – 39300	39950 – 40000	P-P

Frequency division duplex (FDD) systems: the base to subscriber links are preferred in the upper frequency blocks; the subscriber to base links are preferred in the lower frequency blocks. Time division duplex (TDD) systems: may operate in both the lower and upper frequency blocks.

6.1 **IFL Interference** (J. Leland Langston ~~Van der Star~~)

7 Deployment & Coordination

The following paragraphs provide a recommended structure process to be used to co-ordinate deployment of BWA systems in order to minimize interference problems.

7.1 Methodology

Coordination is required between licensed service areas where the shortest distance between the respective service boundaries is less than[1] 60 km and both systems are operating co-channel, i.e. over the same LMDS frequencies. The rationale for 60 km is given in the next section. The operators are encouraged to arrive at mutually acceptable sharing agreements that would allow for the provision of service by each licensee within its service area to the maximum extent possible.

Under the circumstances where a sharing agreement between operators does not exist or has not been concluded, and whose service areas are less than 60 km apart, the following coordination process should be employed (refer to Figure 7-1 for a graphical representation of the process):

LMCS operators are required to calculate the power flux density (pfd) at the service area boundary of the neighboring service area(s) for the LMCS transmitting facilities. Power flux density is calculated assuming line-of-sight free space path loss, including such factors as atmospheric loss, antenna directivity toward the service area boundary, curvature of Earth, and it is the maximum value for elevation points up to 500 m above local terrain elevation. Refer to the next section below for a rationale behind the pfd levels presented in this process. Note the text applies to systems operating in the 20-30 GHz region. A table below is given to address systems that operate outside this range.

Deployment of facilities which generate a pfd less than or equal to -114 dBW/m^2 in any 1 MHz (pfd A) at the other LMDS service area boundaries are not subject to any coordination requirements.

Deployment of facilities which generate a pfd greater than pfd A (-114 dBW/m^2 in any 1 MHz), but less than or equal to -94 dBW/m^2 in any 1 MHz (pfd B) at the other LMCS service area boundaries are subject to successful coordination between the affected licensees in accordance with the following coordination process:

The operator must notify the respective licensee(s) of its intention to deploy the facility(ies) along with the appropriate information necessary to conduct an interference analysis.

The recipient of the notification must respond within 30 calendar days to indicate any objection to the deployment. Objection may be based on harmful interference to existing systems[2] only.

If there is no objection raised, then the deployment may proceed.

If an objection is raised, then the respective licensee(s) must work in collaboration to develop a suitable agreement between the licensee(s) before the deployment of facilities. It is expected that the time frame to develop such an agreement should not exceed 30 calendar days.

Any obligations as a result of the coordination are valid for 120 calendar days from the conclusion of coordination.

Deployment of facilities which generate a pfd greater than - 94 dBW/m^2 in any 1 MHz) (pfd B) at the other LMCS service area boundaries are subject to successful coordination between the affected licensees.

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[1] **In the event an operator using sites of very high elevations relative to local terrain that could produce interference to LMCS service areas beyond 60 km, this operator should coordinate with the affected licensee(s).**

[2] **Existing systems include systems that are operational, or systems that have been co-ordinated previously.**

In any event, licensees are expected to take full advantage of interference mitigation techniques such as antenna discrimination, polarization, frequency offset, shielding, site selection, or power control to facilitate the coordination of systems.

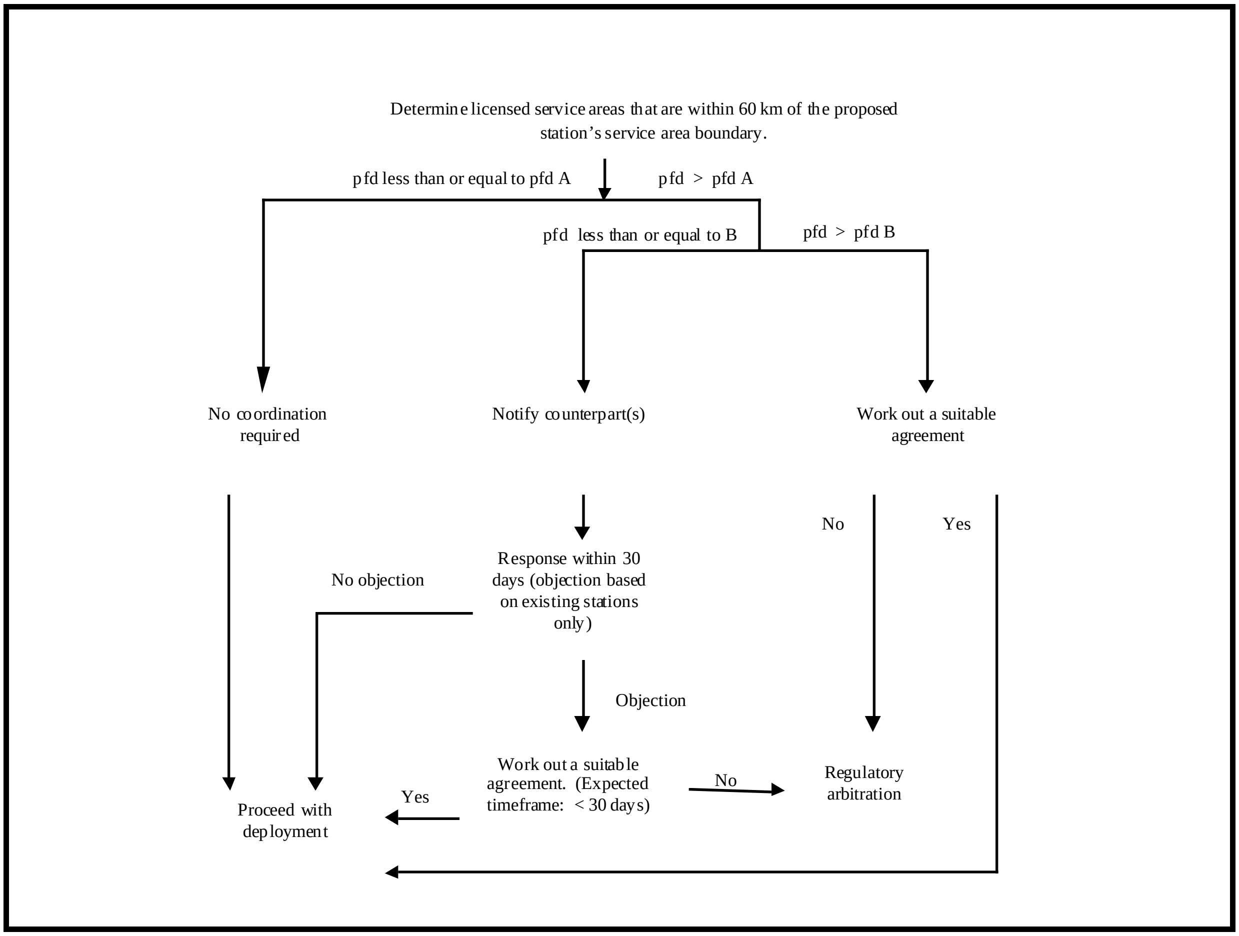

Figure 7-1. Coordination process for adjacent area co-channel LMDS Systems

All results of analysis on pfd, or agreements made between licensees must be retained by the licensees and be made available to the regulatory body upon request.

If a licence is transferred, the sharing agreement(s) developed between the former licensees should remain in effect until superseded by a new agreement between licensees.

In the event a satisfactory agreement or a successful coordination between the licensees is not reached, the regulatory body should be informed.

The table below summarizes the pfd levels for systems operating in the 20-30 GHz and 30-40 GHz bands.

Frequency Band	PFD A (dBW/MHz-m^2)	PFD B (dBW/MHz-m^2)
20-30 GHz	-114	-94
30-40 GHz	-125	-105

Table 7-1. Maximum psfd Limits Allowable without Coordination

7.1.1 Coordination Distance

As described above, distance is used as the first trigger mechanism for coordination between adjacent licensed operators. If the boundary of two service areas is within 60 km of each other, then the coordination process is invoked.

The rationale for 60 km is based upon several considerations including radio horizon calculations, propagation effects, and power flux density levels (the latter is discussed in the next section).

The radio horizon is defined as:

$$R_h = 4.12(\sqrt{h_1} + \sqrt{h_2})$$

where:

R_h = Radio Horizon (km)
h_1 = Height of radio 1 above clutter (m)
h_2 = Height of radio 2 above clutter (m).

The table below presents the horizon range for different radio heights above average clutter.

	Height of Radio 1 (m)								
Height of Radio 2 (m)	10	20	30	40	50	60	70	80	90
10	26	31	36	39	42	45	47	50	52
20	31	37	41	44	48	50	53	55	58
30	36	41	45	49	52	54	57	59	62
40	39	44	49	52	55	58	61	63	65
50	42	48	52	55	58	61	64	66	68
60	45	50	54	58	61	64	66	69	71
70	47	53	57	61	64	66	69	71	74
80	50	55	59	63	66	69	71	74	76
90	52	58	62	65	68	71	74	76	78

Table 7-2. Horizon range for different radio heights (in kilometers).

The worst case interference scenario involves two base stations, as they are typically located on relatively high buildings/infrastructures and hence have greater radio horizon distances. A typical height for a base station is 65 m above ground level, or 55 m above clutter, assuming an average clutter height of 10 m. This produces a radio horizon of 60 km. There will be cases where the base station equipment may be located on higher buildings which would produce a greater radio horizon. However, these base stations tend to tilt their antennas downward which effectively reduces the amount of power (interference) that can be directed towards the adjacent base station. The next section examines power levels in more detail.

7.1.2 Use of Power Spectral Flux Density (psfd) as a Coexistence Metric

This section addresses the maximum power flux density that can be tolerated as a result of co-channel interference originating from an adjacent licensed operator. The amount of interference generally considered acceptable or tolerable is one which produces a degradation of 0.5 dB to the system's C/N (this degradation is usually taken into consideration during the original link budget exercise). For the noise floor to increase by 0.5 dB, the interference power level must be 6 dB below the receiver's thermal noise floor. Assuming a typical receiver noise figure of 6 dB, then the thermal noise power spectral density of the receiver is calculated as follows:

$$N_o = 10Log(kT_o) + N_F$$

$$N_o = -144 + 6 = -138 \text{ dBW/MHz}$$

where,

No = Receiver thermal noise power spectral density (dBW/MHz)

kT_o = Equipartition Law (-144 dBW/MHz)
N_F = Receiver noise figure (6 dB)

At 6 dB below N_o, the interference power level (I_{tol}) into the receiver is -144 dBW/MHz (-138 – 6).

The spectral power flux density (psfd) at the antenna aperture is calculated as follows:

$$psfd = \frac{\Pr}{Ae} = \frac{\Pr}{\lambda^2 \frac{G}{4\pi}} = \Pr - 10Log(\lambda^2) - G + 10Log(4\pi)$$

where:

Pr = interference power level into receiver (-144 dBW/MHz)
Ae = effective antenna aperture
λ = wavelength
G = antenna gain.

Assuming an operating frequency of 28 GHz (λ=.011m) and a typical base station antenna gain of 20 dBi, then the tolerable interference level is given as:

$Psfd_{BTS}$ = -144 - 10Log(.011^2) – 20 + 10 Log(4π) = -144 + 39 – 20 + 11 = -114 dBW/MHz-m^2

Note that the base station receiver is considered only in this analysis (not the subscriber). This is primarily due to the fact that BTS' are typically located on high buildings/structures with omni directional coverage which tend to increase their probability of achieving line of sight (LOS) to adjacent licensed area

transmitters. Subscribers, on the other hand, tend to be situated at low altitudes (~15 m) which significantly reduces the probability of LOS (due to obstacles/clutter) to adjacent area systems. Furthermore, subscribers have highly directional antennas (narrow beamwidths) which further reduces the probability that they will align with an interference source from an adjacent area.

The –114 dBW/MHz-m^2 represents the first PFD trigger level of the coordination process described above.

A sample calculation is given below to determine the feasibility of meeting the pfd limit between a BTS transmitter and BTS victim receiver.. The formula for pfd is as follows:

$$pfd_{victim} = P_{TX} + G_{TX} - 10\log(4\pi) - 20\log(R) - A_{losses}$$

where;

P_{TX} = transmitter power (- 25 dBW/MHz)
G_{TX} = transmitter antenna gain in the direction of the victim receiver (18 dBi)
R = range (60000 m)
A_{losses} = atmospheric losses, ~ 0.1 dB/km

The values given in brackets represent typical LMDS parameters.

Using the radio horizon range of 60 km from above, the pfd at the victim base station receiver antenna is:

pfd_{victim} = -25 + 18 – 10log(4π) – 20log(60000) – 60*.1

= -120 dBW/MHz-m^2

The –120 value is lower than the –114 tolerable level, therefore, the 60 km range is considered reasonable as a first level trigger point. Note that the above pfd calculation assumes free space propagation and clear line of sight, i.e. complete first Fresnel zone clearance.

While spectral pfd A (-114) allows for quick deployment, it is based on fairly conservative assumptions that may unnecessarily limit system performance. Spectral pfd level B is set 20 dB higher on the basis that extra propagation losses will occur in reality, as much as 15 dB from diffraction, and that the operator will be able to resort to basic mitigation techniques including using cross-polarization, placing BTS transmitter at the same frequency as interfering BTS transmitter, etc.

7.1.3 Deployment Process

This section describes a process for an operator to follow in deploying an BWA system to promote coexistence. The process is essentially a 'turn-on' procedural list that should be followed before the operators activate their transmitter(s) to ensure they do not inadvertently interfere with or cause performance degradation to an existing system operating either co-located or in an adjacent area. The operator is highly encouraged to communicate with other known operators who may be potentially affected, since the slightest interference could severely affect their business.

The 'turn on' procedure is as follows:

a. Follow the coordination procedure described above and where applicable, take the necessary mitigation steps accordingly.
b. Scan the roof-top with a detector or spectrum analyzer to determine if any interference is present that may adversely affect the performance of the system to be deployed.
c. Ensure the antennas are properly installed in terms of main beam direction (AZ and El) and polarization (for the latter, labeling on the antenna to clearly indicate polarization is highly recommended). The antennas should also be sufficiently mechanically supported to withstand the worst case local wind conditions such that the antennas only deviate from their original alignment to within [+/- 0.5] degrees.
d. Before turning on the transmitter verify the proper tests have been performed to ensure EIRP and OOB emissions fall within the regulated/ recommended limits.
e. Verify the transmitter EIRP does not exceed safety limits as specified by local regulations.
f. Verify the transmitter or its IF cables do not interfere with IF cables or receivers from other co-located systems.
g. Verify the transmitter will automatically turn off in the event that it becomes rogue i.e. it loses lock and begins to transmit randomly in power and spectrum.

The table below presents the pfd levels for systems operating in the 20-30 GHz band and 30-40 GHz.

Frequency Band	PFD A (dBW/MHz-m^2)	PFD B (dBW/MHz-m^2)
20-30 GHz	-114	-94
30-40 GHz	-125	-105

Table 7-2. Maximum psfd Limits Allowable without Coordination

7.2 Mitigation [TBD]
7.2.1 Antennas
7.2.2 Shielding
7.2.3 Frequency
7.2.4 Spatial Separation

Appendix A - Test and Measurement / Hardware parameter summary

A.1 Testing of Unwanted Emissions

Unwanted emissions are to be measured when the transmitter is operating at the manufacturer's rated power and modulated with signals representative of those encountered in a real system operation. Unwanted emissions are to be measured at the output of the final amplifier stage or referenced to that point. The measurement can be done at the transmitter's antenna connector as long as there is no frequency combiner in the equipment under test. It is important however that the point of measurement for this test be the same as the one used for the output power test. The point of measurement and the *occupied* bandwidth (B_o) should be stated in the test report

Single-carrier and multi-carrier requirements are described below. If multicarrier operations are intended, then both requirements must be met. "Multicarrier" refers to multiple independent signals (QAM, QPSK, …) and does NOT refer to techniques such as OFDM.

The purpose of specifying the tests relative to the virtual block edges is to avoid the attenuating effects of any RF filters that may be included in the transmitter design, so that the spectrum mask limits of section 3.1.2.1 are applicable to any channel block.

Note that although testing is specified relative to the virtual block edges, the transmitter is expected to perform similarly for all frequencies within the designed band. Therefore, to reduce the number of test runs, the Lower Virtual Block Edge can be in one assigned band and the Upper Virtual Block Edge can be in another assigned band.

The search for unwanted emissions should be from the lowest frequency internally generated or used in the device (local oscillator, intermediate or carrier frequency), or from 30 MHz, whichever is the lowest frequency, to the 5th harmonic of the highest frequency generated or used, without exceeding 40 GHz.

A.1.1 Single carrier test

For testing nearest the lower virtual block edge, set the carrier frequency f_L closest to the lower virtual block edge, taking into account any guardband used in the design of the equipment, record the carrier frequency f_L, the virtual block edge frequency f_{VL}, the guardband (f_{LG}) and plot the RF spectrum. Likewise, perform the highest frequency test with the carrier frequency, f_U, nearest the upper virtual block edge. Record the carrier frequency, the virtual block edge frequency (f_{VU}), the guardband (f_{UG}) and the RF spectrum plot. The guardband is the frequency separation between the virtual block edge and the edge (99%) of the occupied emission.

The user manual should contain instructions, such as details on the minimum guardband sizes required to ensure that the radios remain compliant to the certification process.

It is to be noted that the regulations may permit licensees to have more than one frequency block for their systems. Equipment intended to have an occupied bandwidth wider than one frequency block per carrier should be tested using such a wideband test signal for the section 3.1.2.1(1) requirement.

A.1.2 Multi-carrier test.

This test is applicable for multi-carrier modulation (not OFDM). It applies equally to multi-transmitters into a common power amplifier. Note that the multi-carrier transmitter must be subjected to the single carrier testing, described above, in addition to the tests specified below.

For multi-carrier testing, the single carrier test method of A.x.1 is to be used except that the single carrier is replaced by a multi-carrier modulated signal that is representative of an actual transmitter. The number of carriers should be representative of the maximum number expected from the transmitter, and be grouped side by side nearest the lower virtual block edge, with lower guardband, f_{LG}, if required by the design of the equipment. Likewise test nearest the upper virtual block edge. Record their spectrum plots, the number of carriers used and the guardband sizes ($f_{LG,}$ f_{UG}), the carrier frequencies and the virtual block edge frequencies.

Notwithstanding the requirements in the table in section 3.1.2 “Minimum Separation between Actual and Virtual Block Edge”, any equipment which uses the complete block or multiple blocks for a single licensee can include the attenuating effect of any RF filters in the transmitter design within the multi-carrier test , in which case the Virtual and Actual block edge frequencies will be the same.

The user manual should contain instructions, such as details on the minimum guardband sizes required and the maximum number of carriers or multi-transmitters permitted, to ensure that the radios remain compliant to the testing process.

A.2 Measuring Frequency Stability. (keith)

As discussed in section 3.1.3, the RF carrier frequency should not depart from the reference frequency (reference frequency is the frequency at 20^{o}C and rated supply voltage) in excess of $\pm$ 10 ppm. The RF frequency of the transmitter should be measured:

(a) At temperatures over which the system is designed to operate and at the manufacturer's rated supply voltage. The frequency stability can be tested to a lesser temperature range provided that the transmitter is automatically inhibited from operating outside the lesser temperature range. If automatic inhibition of operation is not provided the manufacturer’s lesser temperature range intended for the equipment is allowed provided that it is specified in the user manual.

(b) At 85% and at 115% of rated supply voltage, with temperature at $+20^{o}$ C .

In lieu of meeting the above stability value, the test report may show that the frequency stability is sufficient to ensure that the occupied bandwidth emission mask stays within the licensee’s frequency band, when tested to the temperature and supply voltage variations specified above. The emission tests should be performed using the outermost assignable frequencies which should be stated in the test report.

Appendix B – Abbreviations and Glossary

This appendix contains a list of definitions and abbreviations contained in this document.

ABBREVIATIONS

BTA	Basic Trading Area
BTS	Base Transceiver Station
BWA	Broadband Wireless Access
CPE	Customer Premise Equipment
DL	Downlink
FDD	Frequency Division Duplex
EIRP	Effective Isotropic Radiated Power
EIRPSD	Effective Isotropic Radiated Power Spectral Density
FDMA	Frequency Division Multiple Access
ICL	Inband Intercell Links
LMCS	Local Multipoint Communication System (Canadian version of LMDS)
LMDS	Local Multipoint Distribution Service (U.S. FCC Definition)
LOS	Line of Sight
Mbits/s	Megabits per second
MP	Multipoint
OFDM	Orthogonal Frequency Division Multiplexing
PMP	Point-to-Multipoint
ppm	Part per Million (10^{-6})
PTP	Point-to-Point
RX	Receive
QAM	Quadrature Amplitude Modulation
RS	Repeater Station
SRSP	???
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TX	Transmit
UL	Uplink

GLOSSARY

Base Station	The assemblage of hardware including antenna(s), transmitters, receivers, modem functions, network functions, control functions, etc. at a geographic point within a BWA network which provides network access to multiple subscribers located within the service region of the base station in a PMP system.
Broadband:	Having instantaneous bandwidths greater than around 1 MHz and supporting data rates greater than 1.5 Mbps.
Broadband Wireless Access	The delivery of broadband service from a BTS to CPE using wireless technology
Downlink	RF transmissions from the BS to the CPE
DS-3	A North American Common Carrier Multiplex Level in a TDM system having a line rate of 44.736 Mbps.
Frequency Division Duplex	A duplex scheme where transmission occurs simultaneously on the Uplink and Downlink path using diffeent frequencies.
Guardband	The difffeence between the upper (lower) edge of the band containing the Upstream frequency channel(s) and the lower (upper) edge of the band containing the downstream channel(s) in an FDD system. This guard band is used in an FDD system to provide adequate frequency separation between the two paths.
Multi-Carrier System	The use of two or more carriers to provideservice from a single transmitter.
Multipoint	A wireless topology where a single base station provides service to multiple subscribers located within the coverage area of the base station, and the subscribers are in geogrphically diffeent locations with respect to each other.The sharing of resources may occur in the time domain, frequency domain, or both.
OC-3	One hiarichal level in the Synchronous Optical Network (SONET) transmission standard. The line rate for this level is 155.52 Mbps.
Power Control	A technique used BWA systems to actively adjust the transmit power of a transmitter to maintain the received signal level within some desired range.
Repeater	A device used to receive, amplify and retransmit information along a communications channel . In BWA systems, a repeater may be used to either extend the range of a link or compensate for non-LOS conditions.
Time Division Duplex	A duplex scheme where Uplink and Downlink transmissions occur at diferent times while sharing the same frequency.
Uplink	The transmissions of information from the subscriber to the Base Station.

C.1 Base Station Antenna Parameters

Table C-1. Class 1 - Azimuth RPE

Angle off-boresight (deg)	Class 1 Maximum Relative Gain (dB)	Class 1 Minimum Relative Gain (dB)
0	0	-3
α	0	-3
2 * α	-10	
3 * α	-18	
155	-25	
180	-25	

Use linear interpolation between limits.

Table C-2. Class 2 - Azimuth RPE**In terms of α, where α equals _ the 3 dB beamwidth:**

Angle off-boresight (deg)	COPOL Recommended Maximum Relative Gain (dB)	COPOL Recommended Minimum Relative Gain (dB)	CROSSPOL Recommended Maximum Relative Gain (dB)
0	0	-3	-25
α	0	-3	-30
α+5			
α+15			
2 * α	-20		
2.44 * α			
3 * α	-30		
155	-30		
180	-30		-30

Use linear interpolation between limits.

Table C-3. Class 3 Azimuth RPE

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

For α ≥ 30 degrees:

Angle off-boresight (deg)	COPOL Recommended Maximum	COPOL Recommended Minimum	CROSSPOL Recommended Maximum

	Relative Gain (dB)	Relative Gain (dB)	Relative Gain (dB)
0	0	-3	-28
α		-3	
α+5	0		
α+15	-20		-30
2.44 * α	-29		-35
140	-35		-35
180	-35		-37

Use linear interpolation between limits.

For α < 30 degrees:

Angle off-boresight (deg)	COPOL Recommended Maximum Relative Gain (dB)	COPOL Recommended Minimum Relative Gain (dB)	CROSSPOL Recommended Maximum Relative Gain (dB)
0	0	-3	-28
α		-3	
α+5	0		
α+15	-20		-30
2.44 * α	-29		-35
5 * α	-35		-35
180	-40		-37

Use linear interpolation between limits.

Table C-4. Class 1 Elevation RPE.

Angle (deg)	Above the Horizon **COPOL Recommended Maximum Relative Gain (dB)**	Below the Horizon **COPOL Recommended Minimum Relative Gain (dB)**	**Above and Below the Horizon CROSSPOL Recommended Maximum Relative Gain (dB)**

-90		-80	-25
-40		-80	
-15		-40	
-5		-15	
0	0	-3	-22
5	0		
7	-3		
20	-16		
40	-20		
90	-30		
180	-30		-25

Use linear interpolation between limits.

Table C-5. Class 2 Elevation RPE

Angle (deg)	Above the Horizon **COPOL Recommended Maximum Relative Gain (dB)**	Below the Horizon **COPOL Recommended Minimum Relative Gain (dB)**	Above and Below the Horizon **CROSSPOL Recommended Maximum Relative Gain (dB)**
-180		-80	-35
-90		-80	-30
-45		-80	
-30		-34	
-20		-28	
-15		-24	
-5		-22	
0	0	-3	-25
4	-3		
15	-18		
90	-35		-30
180	-35		-35

Use linear interpolation between limits.

Table C-6. Class 3 Elevation RPE

Angle (deg)	Above the Horizon **COPOL Recommended Maximum Relative Gain (dB)**	Below the Horizon **COPOL Recommended Minimum Relative Gain (dB)**	Above and Below the Horizon **CROSSPOL Recommended Maximum Relative Gain (dB)**
-180		-80	-35

-90		-80	-30
-45		-40	
-30		-28	
-20		-28	
-15		-22	-30
-10		-20	
-5		-12	-28
0	0	-3	-25
4	-3		
15	-18		
90	-35		-30
180	-35		-35

Use linear interpolation between limits.

C.2 CPE Antenna Parameters

Table C-7. Directivity Category 1– Co-polar

Degree off bore axis	**Class 1**	**Class 2**	**Class 3**
0	0	0	0
2α	0	0	0
5	-10	-14	-20
10	-18	-22	-30
60	-25	-30	-40
80	-30	-35	-45
90	-35	-40	
100	-40	-45	-50
180	-40	-45	-50

Table C-8. Directivity Category 1– Cross-polar

Degree off bore axis	**Class 1**	**Class 2**	**Class 3**
0≤ angle <5	-27	-27	-30
5	-30	-30	-30
10	-35	-35	-40
60		-43	-45
80			
90	-40	-45	-50
100	-40	-45	-50
180	-40	-45	-50

Table C-9. Directivity Category 2– Co-polar

Degree off boresight axis	**Class 1**	**Class 2**	**Class 3**
0	0	0	0
2α	0	0	0
5	-14	-14	-25
10	-20	-22	-30
60	-27	-35	-40
100	-45	-50	-55
180	-45	-50	-55

Table C-10. Directivity Category 2– Cross-polar

Degree off boresight axis	**Class 1**	**Class 2**	**Class 3**

0≤ angle <5	-27	-27	-27
5	-30	-30	-30
10	-35	-35	-40
60			-50
100	-45	-50	-55
180	-45	-50	-55

Table C-11. Directivity Category 3– Co-polar

Degree off boresight axis	**Class 1**	**Class 2**	**Class 3**
0	0	0	0
2α	0	0	0
4α	-10	-10	-10
5	-19	-19	-25
10	-25	-27	-35
60	-32	-40	-45
100	-50	-55	-60
180	-50	-55	-60

Table C-12. Directivity Category 3– Cross-polar

Degree off boresight axis	**Class 1**	**Class 2**	**Class 3**
0≤ angle <5	-30	-30	-30
5	-35	-35	-35
10	-40	-40	-45
100	-50	-55	-60
180	-50	-55	-60