Two System Proposal

# Deployment of Two Cross-Polarized Systems in the ATG Band

**Prepared for**

Federal Communications Commission

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# 1. Introduction

This document outlines a revised AirCell proposal to accommodate two broadband, deck-to-deck systems in the ATG band. Under this plan, the ATG spectrum is shared by two systems operating on orthogonal polarizations and frequency offsets. This method of spectrum sharing was considered in previous AirCell submissions to the FCC [2,7]. Document [2] provided a proof of concept, while presenting operation within the framework of a four-system deployment that also relied upon cross-duplexing as a system isolation technique. In the current proposal, cross-polarized and frequency offset (XP) operation is presented in the context of a two-system deployment. Rules related to base-base separation distances, required to support cross-duplexing isolation, are no longer needed. Under this revised plan, carrier sites serving the same airspace will need to be located in close proximity to one another (to control near-far effects). Overall, the spectrum sharing rules are significantly simplified and deployment of competitive systems will be easier under this plan. Also, concerns regarding the potential impact of the Naval air search radar become moot, as all aircraft receive frequencies are now in the same band.

AirCell's system simulator was used to evaluate the performance of the proposed XP plan. Two scenarios, Airport and Cross-Country, were evaluated. The impact on the forward link is less than 1.2 dB 99% of the time for the Cross-Country scenario, and less than 2.0 dB 99% of the time for the Airport scenario. On the reverse link, spectrum sharing causes a noise rise that is smaller than 0.5 dB 99% of the time when system loading is at 50% of the pole point, for both the Airport and Cross-Country scenarios. For a system loading of 75% relative to the pole point, the noise rise increase is smaller than 2 dB for 99% of the time. These results indicate a negligible impact of XP spectrum sharing on the performance of the two competitive systems.

The use of cross-polarization is not new. AirCell currently uses cross-polarization in providing ATG service in the cellular bands as part of a successful spectrum sharing strategy that has been thoroughly reviewed and approved by the Commission and has been operating for six years with no reports of interference. Moreover, the Commission has recognized cross-polarization as an accepted means of sharing spectrum and as an effective interference mitigation technique in other services. For example, the Commission has incorporated cross-polarization into its satellite rules,[1] noting that "this technique is used extensively" because "it facilitates re-use of frequencies to accommodate multiple signals, thereby promoting efficient use of the spectrum."[2]

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[1]/ *See, e.g.*, 47 C.F.R. §25.214(c)(4) (permitting SDARS licensees to employ cross-polarization for spectrum sharing); 47 C.F.R. §25.258 (b) (rules for NGSO MSS and GSO FSS sharing in the 29 GHz band).

[2]/ Establishment of Rules and Policies for the Digital Audio Radio Satellite Service in the 2310-2360 MHz Frequency Band, *Report and Order, Memorandum Opinion and Order and Further Notice of Proposed Rulemaking*, 12 FCC Rcd 5754 (1997) at ¶ 122. The Commission also previously recognized the interference mitigation benefits of cross-polarization in the MMDS and ITFS contexts. *See* 47 C.F.R. § 21.938 (requiring consideration of "interference abatement techniques such as cross polarization"); Amendment of Parts 1, 21, and 74 to Enable Multipoint Distribution Service and Instructional Television Fixed Service Licensees to Engage in Fixed Two-Way Transmissions, *Report and Order and Further Reconsideration and Further*

In summary, we believe this revised proposal to be an attractive alternative, allowing two carriers to offer competitive broadband deck-to-deck service, while requiring minimal rules and/or ongoing coordination between carriers.

## 2. Proposal Description

Deployment of the two XP systems in the ATG band requires accommodation of the existing legacy narrowband operation. Therefore, the deployment is performed in two stages. In the first stage, the two broadband systems coexist with the legacy system in a spectrum allocation as proposed in Figure 1. In this stage, the narrowband system occupies the upper 500 kHz of the band, while the lower 1.5 MHz portions are shared by broadband systems with a 100% spectrum overlap. When the narrowband system is phased out, the two broadband systems are staggered in the frequency domain to a point of 60% spectrum overlap. The final spectrum allocation is presented in Figure 2. Both the transitional and the final spectrum plans provide 125 kHz of guard band between the wideband systems and adjacent bands. According to filings recently submitted to the FCC by Qualcomm [3] and Flarion [4], this guard band is sufficient to permit safe and interference-free deployment of either CDMA or OFDM based systems.

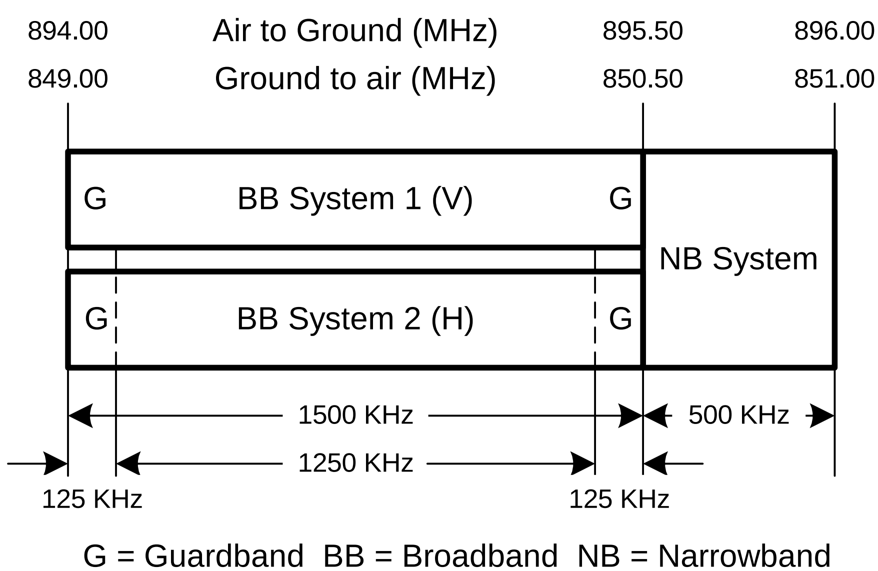


**Figure 1.** Initial ATG spectrum allocation

*Notice of Proposed Rulemaking*, 15 FCC Rcd 14566 (2000) at ¶ 19 (noting the use of cross-polarization to minimize intra- and inter-system interference).

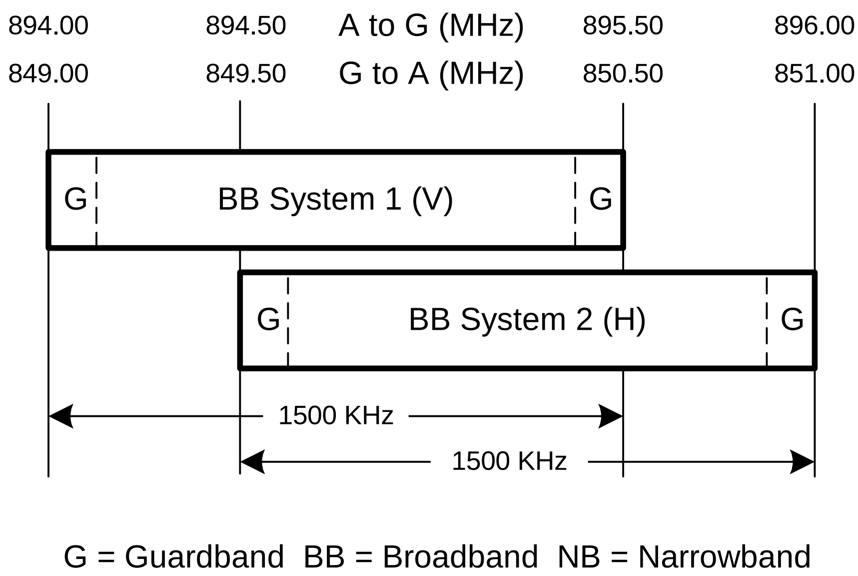


**Figure 2.** Final ATG spectrum allocation

## 2.1. *Inter-System Isolation Mechanisms*

When two systems are deployed in a XP mode, the only interference potential exists from the so-called near-far problem. To explain the nature of the near-far problem, consider the situation depicted in Figure 3. The aircraft in Figure 3 is subscribed to System 1. It is at a location far from the serving System 1 base station and near a base station of System 2. The aircraft is power controlled by System 1 and, since it is far from the closest serving BS, it is transmitting at a high power level.

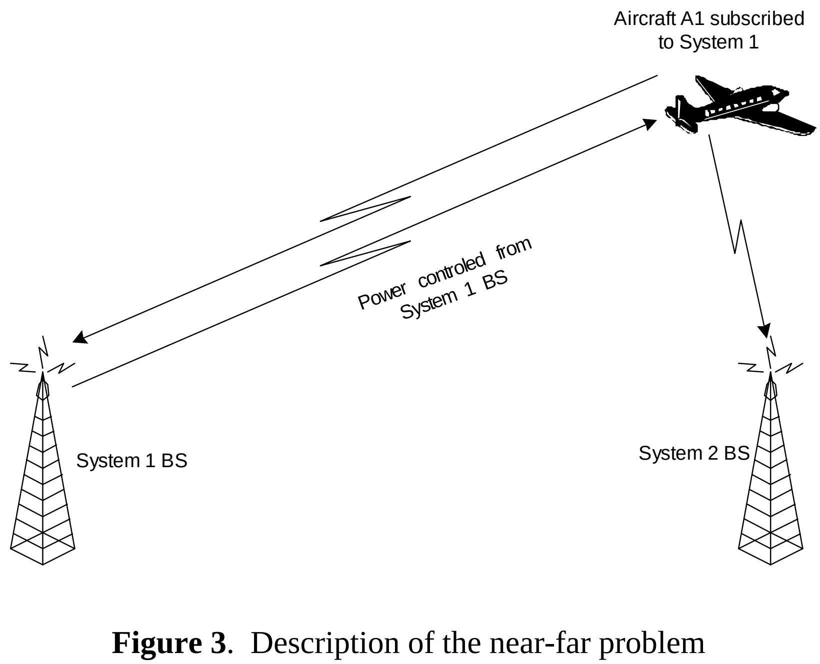


**Figure 3**. Description of the near-far problem

Given that the two systems share the same spectrum, high power transmissions from the aircraft may create substantial interference to the System 2 BS receiver. At the same time, on the forward link, the signal from System 2 BS may cause a high level of interference to an already weak signal that the aircraft receives from the BS of System 1.

The XP deployment relies on two isolation mechanisms to provide a guard against the near-far problem.

1. *Cross-polarization*. The two systems transmit using orthogonal polarizations. Use of the orthogonal polarization provides nominally 12-15 dB of isolation between systems using horizontal and vertical polarizations (see Attachment A, Exhibit B-7 of [5][3]). Referring back to Figure 3, in order to cause *harmful interference*, the signal from the Aircraft A1 needs to be at least 12 dB stronger than the signals from the aircraft served by the System 2 base station.
2. *Partial spectrum overlap*. In the final stage spectrum plan, the two systems are deployed with only a partial spectrum overlap. This further reduces the cross system interference by additional 2.22 dB.[4]

In order to preserve the isolation available from these mechanisms, it is necessary to properly engineer the sites.

1. *Comparable path losses to serving locations*. A more careful inspection of the near-far problem presented in Figure 3 reveals that it can only exist if the two cell sites are widely separated. If the cell sites are close to each other, the power control of aircraft A1 would be essentially the same from either base station location. Therefore, except for possible difference in loading between the two sites, it becomes irrelevant if the aircraft transmit power is controlled from either the System 1 or System 2 base station. Since CDMA systems are typically operated with a maximum noise rise of 6 dB, the maximum total of signals of the aircraft on system 1 will be –109 + 6 = -103 dBm. The cross-polarization isolation and partial spectrum overlap (under the post-transition band plan) will reduce the total signal to –103 – 12 – 2.2 = - 117.2 dBm, or 8.2 dB below the Thermal Noise Floor for System 2. Therefore, in the case of the nearby sites, the impact of near-far problem effects is essentially nonexistent.
2. *Comparable site configurations*. Antenna patterns must have minimal differences in order to avoid differences in aircraft transmit power that would be a function of different gain characteristics of the System 1 or System 2 base station antennas.
3. *Controlled gain patterns on antennas*. The minimum altitude of the served aircraft as well as the cell size governs the maximum near-far exposure. By controlling the gain pattern of the serving antenna, it is possible to reduce the proximity requirements of sites of the two systems. By utilizing antennas with a maximum gain of -20 dB relative to the main lobe over the range of angles of 15° above the horizon to 90° above the horizon, the

[3] The document [5] is the document that should have been referred to as [7] in AirCell's submission dated June 29, 2004, *Evolution of the ATG Migration Concept (Part2)*, rather than *Final Report of AirCell Flight Tests*, which was referenced in error.

[4] The spectrum overlap in the final stage is 60%. Therefore the nominal interference reduction can be calculated as $10\log(0.6) = -2.22$ dB.

near-far effect is effectively eliminated for “split” sites located between two primary sites. Matching sites are therefore not required for split sites when such antennas are utilized.

# 3. Two Licensee Spectrum Sharing Rules

The two licensee spectrum sharing rules for XP deployment are summarized as follows:

## 3.1. *Licensee and Spectrum Allocation*

The frequencies in Table 1 indicate the Transmit frequencies of the Ground and Air stations. Initially, existing ATG services must move to channel blocks in the upper 500 kHz of the bands and clear the remaining channel blocks. To provide a transition period for the phase-out of the current narrowband ATG system, channel assignments for the broadband systems are initially fully overlapped. Final channel assignments shall apply once the incumbent has discontinued use of the narrowband service.

The channel assignments reflect 3 MHz (2 x 1.5 MHz) per licensee.

**Table 1.** Spectrum allocation for two-licensee proposal

| System | Pol | Initial Channels (MHz) | | Final Channels (MHz) | |
|---|---|---|---|---|---|
| | | Ground | Air | Ground | Air |
| Existing | V | 850.50 - 851.00 | 895.50 - 896.00 | - | - |
| System 1 | V | 849.00 - 851.50 | 894.00 - 895.50 | 849.00 - 851.50 | 894.00 - 895.50 |
| System 2 | H | 849.00 - 851.50 | 894.00 - 895.50 | 849.50 - 851.00 | 894.50 - 896.00 |

## 3.2. *BTS (Base Station) – Location, Distance and Power Levels*

### 3.2.1 Initial Site Locations:

The two carriers shall locate their base stations within 5 miles of each other for the initial sites providing cross-country service (*i.e.*, the initial “grid” of sites providing coverage above 10,000’). Airport sites shall be located within 2 miles of each other, where airport sites are those providing coverage for aircraft flying below 10,000’. The initial grid of cross-country sites may utilize the reference locations listed in 47 CFR 22.859 of the Commissions Rules, or, by agreement, the carriers may agree upon an alternative set of design guidelines and sites. The list of sites may be amended from time to time by mutual agreement of the carriers.

### 3.2.2 Antenna requirements:

The two carriers may agree upon antenna patterns for each (or all) site location that will provide adequate near-far isolation. The default antenna requirements could be:

- Gain of 11 dBi towards the horizon, with a maximum 3 dB of cable loss for antenna cables, connectors, etc.

- Maximum sidelobes of -20 dB relative to the main beam over the range of 15 degrees above the horizon to 90 degrees above the horizon
- Sectorized sites shall have comparable gain characteristics, considering the effective aggregate gain of the sector antennas utilized.

### 3.2.3 Transmit power level requirements:

The two carriers may agree upon any transmit power level to be used for each (or all) site locations. The default transmit power level could be:

- +53 dBm EIRP (*i.e.*, 41 dBm transmitter output adjusted for tx cable loss that is less than 3 dB)

The two carriers may agree upon any transmit power level to be used for aircraft. The default transmit power level could be:

- +23 dBm EIRP

### 3.2.4 Construction requirements / aircraft transmitter control:

Carriers are not required to construct a site corresponding to agreed site location. However, for sites not constructed, aircraft transmitters shall be controlled to avoid creating near-far interference to the other system by either:

- disabling aircraft transmission below 10,000’ AMSL,

– or –

- providing an alternative transmitter control capability that shall assure that aircraft served by one carrier cannot cause near-far interference to the other carrier’s base station (*e.g.*, by detecting forward link signals from the other base station and reducing transmit power to a level that will not generate a signal greater than 3 dB below the TNF)

## 4. Performance Analysis

To evaluate performance of the various deployment scenarios, AirCell has developed a custom system level simulator. The simulator is based on 1xEvDO rev 0 and it is explained in greater detail in [1,4]. Analyses presented in this document are quite similar to those already reported in [2]. The differences in the simulations are in the following elements:

1. The antenna on the aircraft is modeled as a half-wave dipole, rather than with a hemispheric pattern, as in [1,4]).
2. Base stations of the two systems are modeled at the same locations.
3. The focus of the presented results is on a comparison of the system performance indicators between the cases where there is a single broadband system compared to where there are two broadband systems with XP isolation implemented.

Paralleling the approach from previous AirCell reports, the results are presented for two typical operational scenarios: Airport and Cross-Country. The Airport scenario cell layout is changed with respect to the one used in [1,4], with site placement as shown in Figure 4. The most important difference is the introduction of the airport site in proximity of the airport location, supporting deck-to-deck coverage. At the same time, the altitude of the aircraft flying in the area of the airport follows the "approach-bowl" that was described in [7]. In this way, the performance around the airport is tested in the case of "deck-to-deck" coverage. Further details on the two scenarios can be found in [1,4].

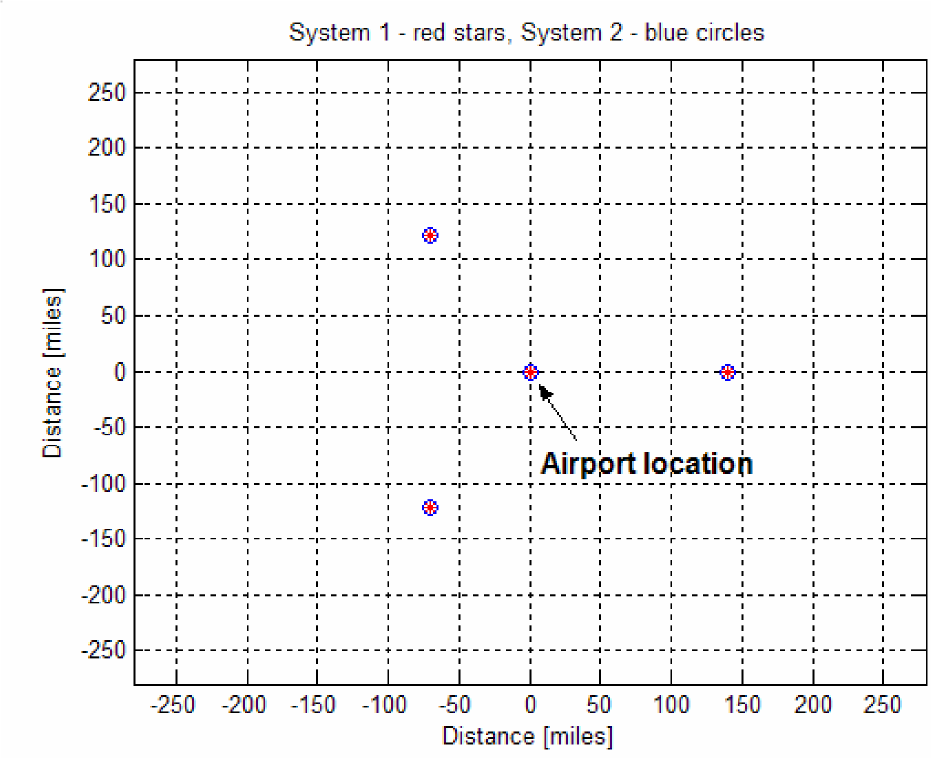


**Figure 4.** Cell site locations in the airport scenario

Three performance indicators are considered[5]:

1. Degradation in the forward link (ground to air) SINR
2. Increase in the aircraft transmit power
3. Increase in the base station noise rise

For each performance indicator, the simulations are used to produce a degradation plot. A sample of such plot for forward link SINR is presented in Figure 5. Along the x-axis is the level of degradation - in this case the reduction of the forward link SINR, expressed in dB. On the y-axis is the probability of observing the degradation level. For example, for the chart presented in

[5] Earlier AirCell report [6] presented the forward link traffic SINR as well. This indicator was used to evaluate the benefits that one obtains from the switched beam antennas. In this report this analysis is omitted since it is reasonable to assume that the switched beam antennas would not be part of the initial system deployment.

Figure 4, one finds that the probability of experiencing SINR degradation of 1dB is approximately 1%.

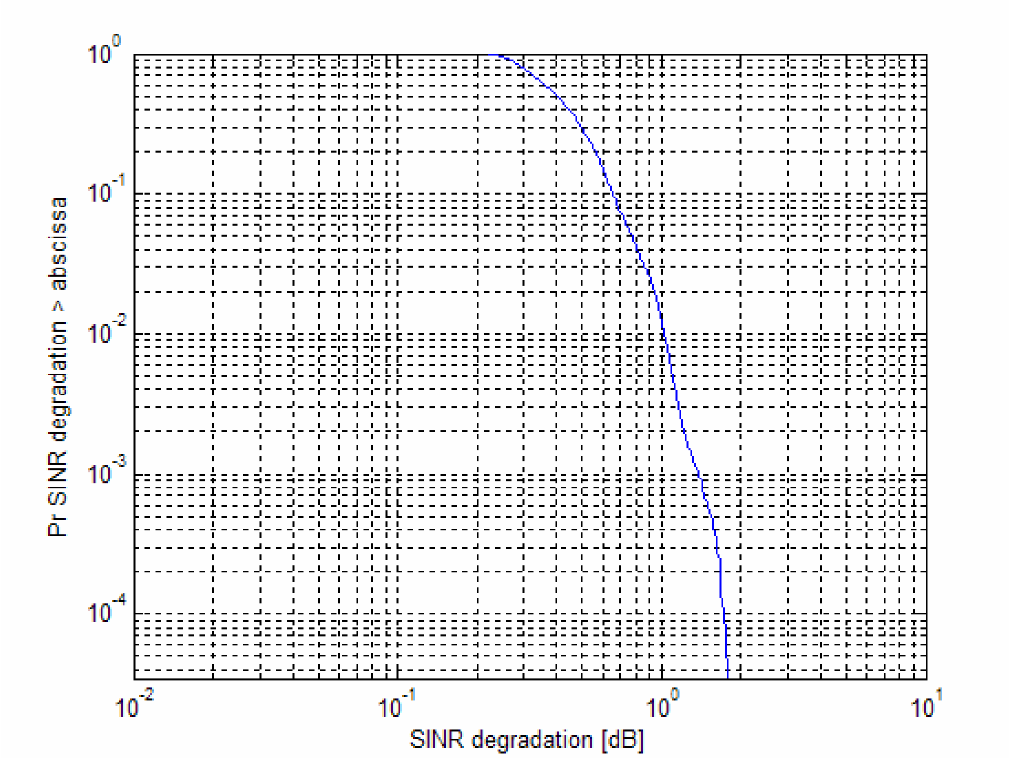


**Figure 5.** Sample degradation plot for forward link SINR

### 4.1. *Cross-country Scenario*

The performance impact plots for the cross-country scenario are presented in Figs 6 through 8. The performance plots are derived for three different levels of system loading (25%, 50% and 75%). The loading is defined with respect to the pole point. The results are summarized in Table 3. The table provides expected level of degradation for 10% and 1% of the time.

**Table 3.** Summary of the degradation levels for 10% and 1% of the time thresholds

| Percent of time [%] | 10 | | | 1 | | |
|---|---|---|---|---|---|---|
| Loading [%] | 25 | 50 | 75 | 25 | 50 | 75 |
| Degradation in SINR [dB] | 0.7 | 0.70 | 0.7 | 1.1 | 1.2 | 1.2 |
| Increase in TX power [dB] | 0 | 0.25 | 0.9 | 0.13 | 0.4 | 1.8 |
| Increase in the NR [dB] | 0.08 | 0.25 | 0.9 | 0.13 | 0.4 | 1.8 |

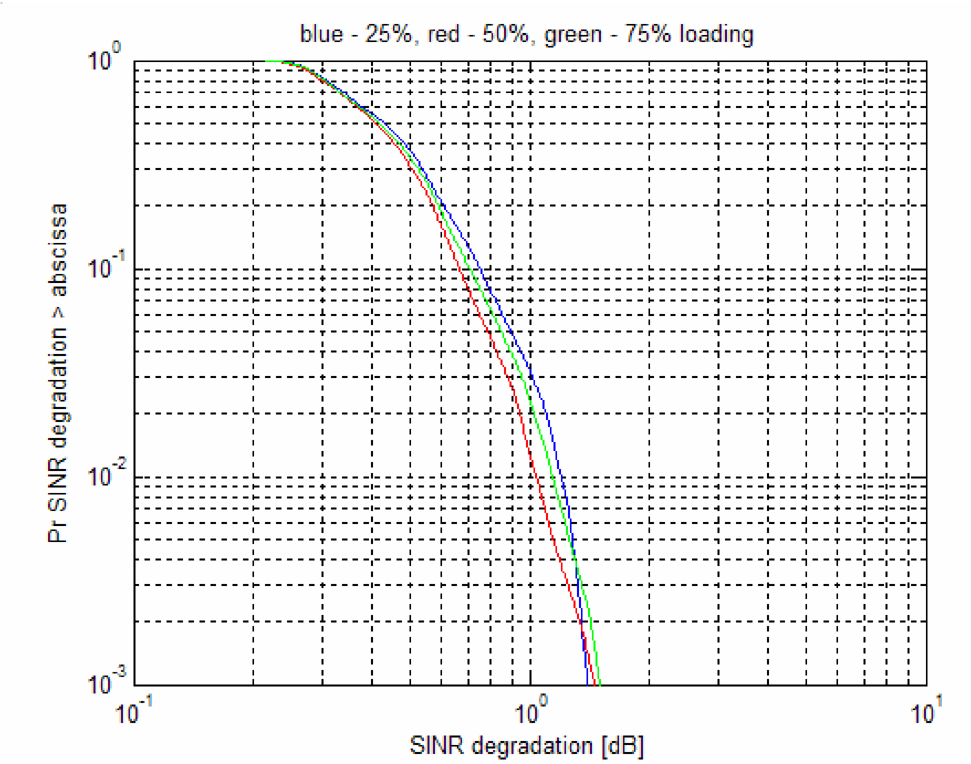


**Figure 6.** SINR degradation plot – Cross-Country scenario

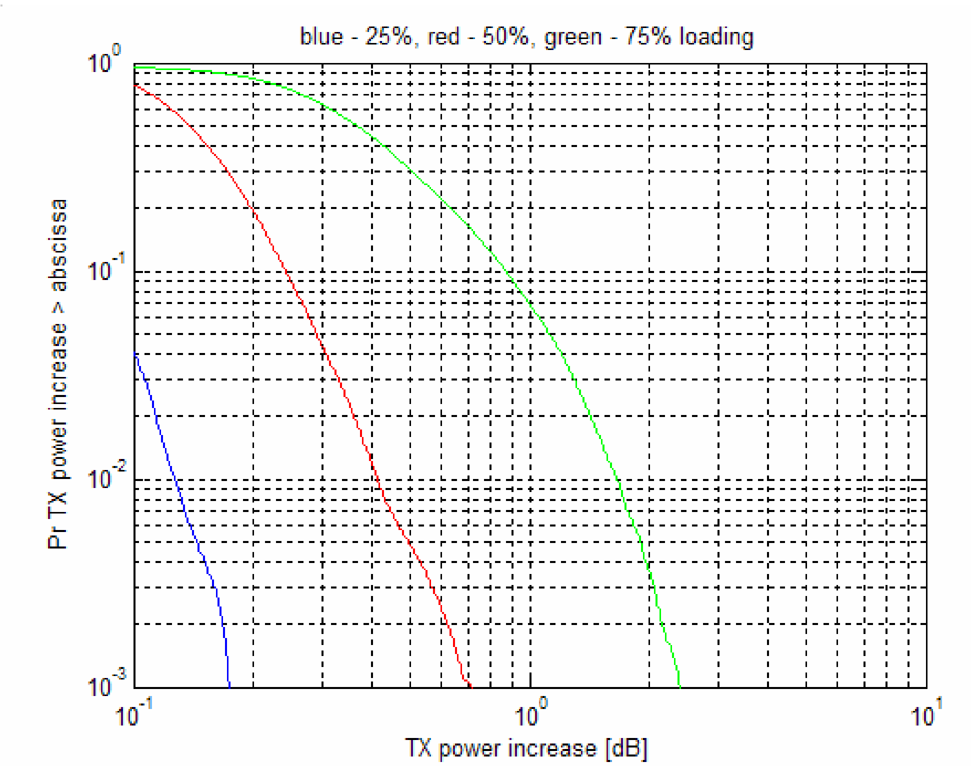


**Figure 7.** Reverse link transmit power increase – Cross-Country scenario

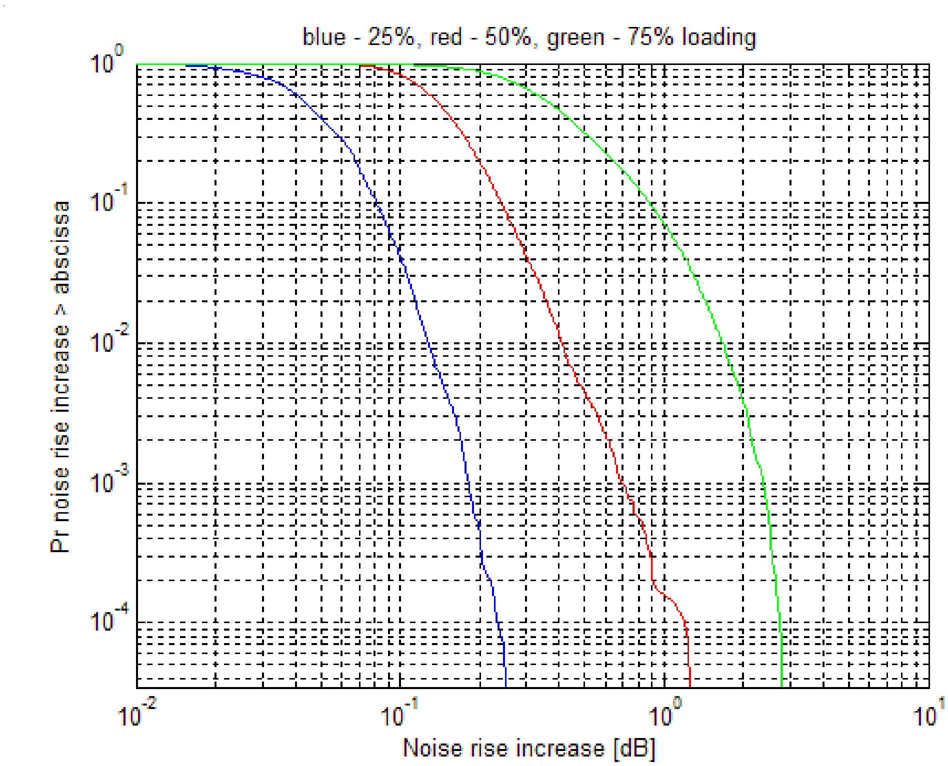


**Figure 8.** Reverse link noise rise increase – Cross-Country scenario

## 4.2. *Airport Scenario*

The performance impact plots for the airport scenario are presented in Figs 9 through 11. The performance plots are derived for three different levels of system loading (25%, 50% and 75%). The loading is defined with respect to the pole point. The results are summarized in Table 4. The table provides expected level of degradation for 10% and 1% of the time.

**Table 4.** Summary of the degradation levels for 10% and 1% of the time thresholds

| Percent of time [%] | 10 | | | 1 | | |
|---|---|---|---|---|---|---|
| Loading [%] | 25 | 50 | 75 | 25 | 50 | 75 |
| Degradation in SINR [dB] | 1.3 | 1.3 | 1.3 | 2 | 2 | 2 |
| Increase in TX power [dB] | 0 | 0.25 | 0.65 | 0.17 | 0.5 | 2 |
| Increase in the NR [dB] | 0.09 | 0.25 | 0.65 | 0.17 | 0.5 | 2 |

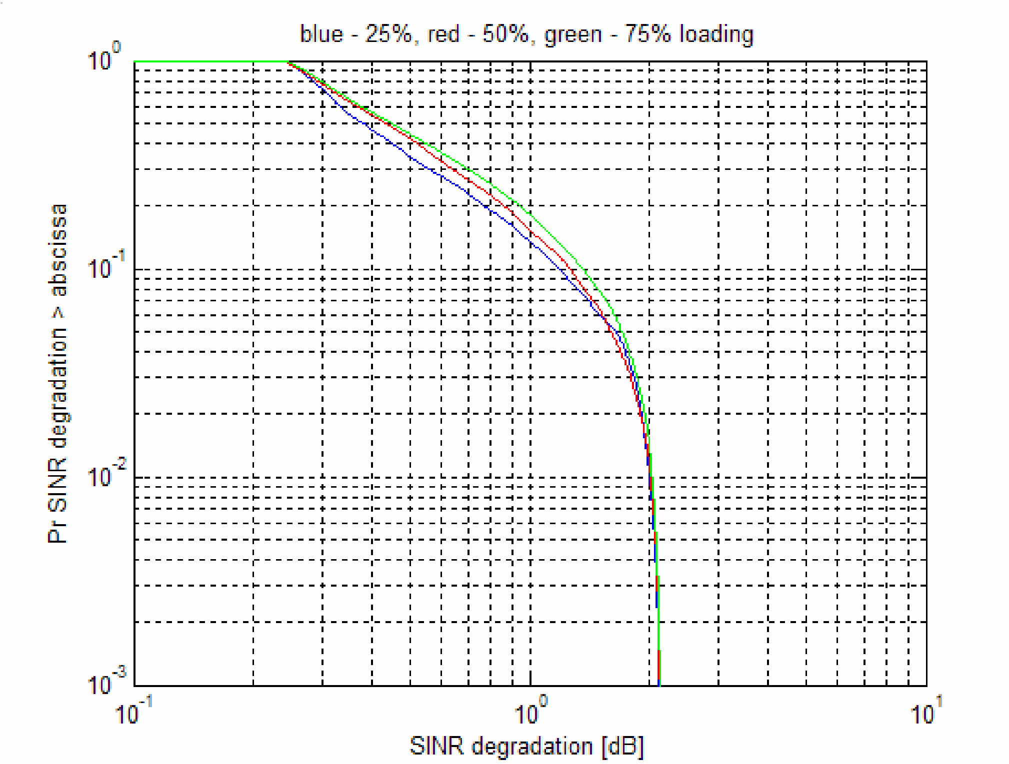


**Figure 9.** SINR degradation plot – Airport scenario

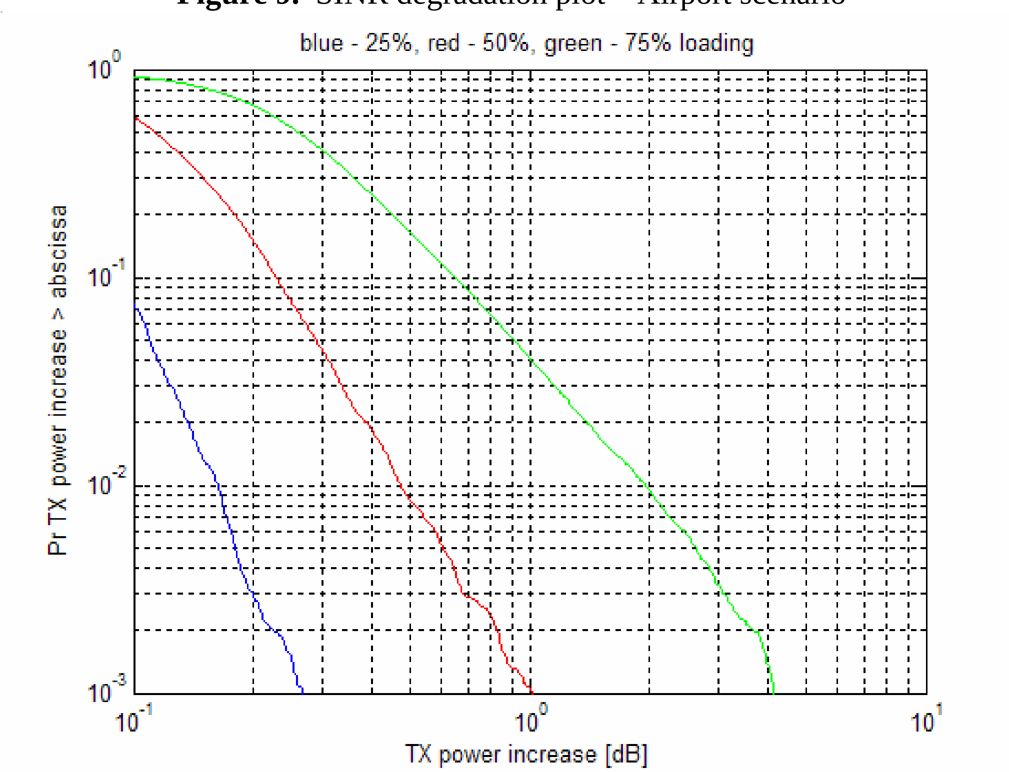


**Figure 10.** Reverse link transmit power increase – Airport scenario

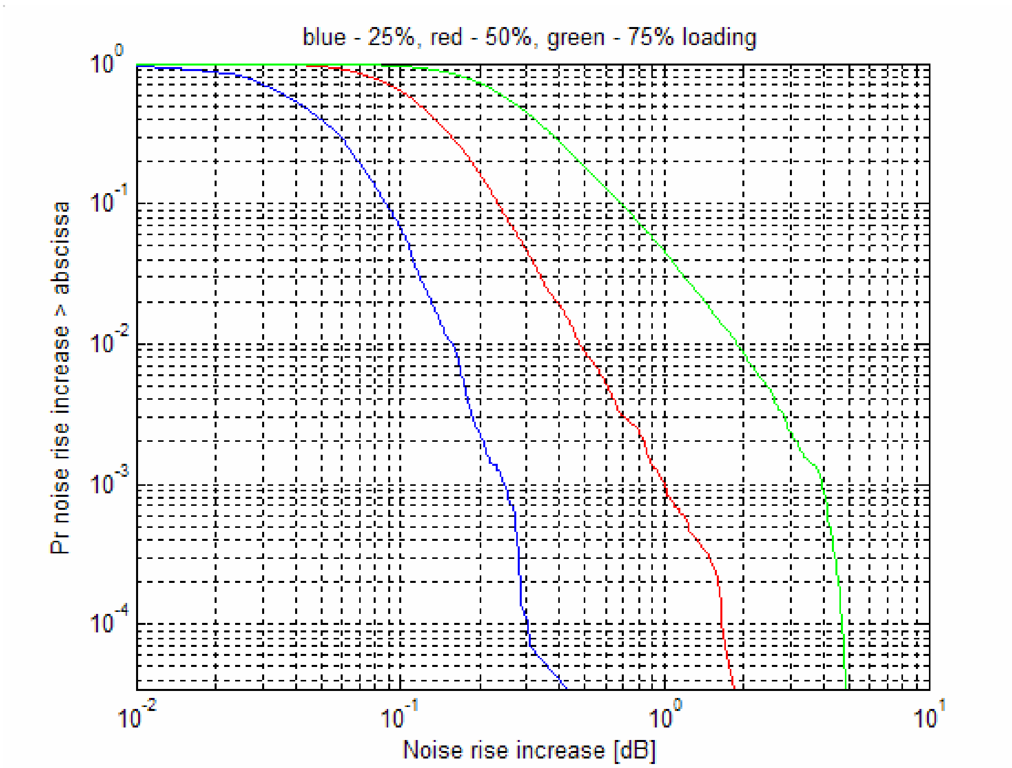


**Figure 11.** Reverse link noise rise increase – Airport scenario

### 4.3. *Inter-system site spacing for cross-country sites*

The impact of site spacing between two sites (of the two systems) serving the same airspace is most evident when aircraft are flying at lower altitudes, and when cell radii are small. Figure 12 below shows the impact of site spacing for a cell radius of 50 miles, considering the impact on aircraft flying at 10,000' altitude. Figure 13 shows the impact on reverse link interference for the same situation.

The D=0 plot is the "baseline," the impact if sites from the two systems are collocated. For values of D=1,2, and 5, there is very little impact on the SINR degradation or the level of reverse link interference generated. It is therefore suggested that a value of 5 miles be used for the maximum intersystem site spacing. Note that the impact of increasing the value of D is gradual. It is clear that this rule could be relaxed, especially in areas where cell splitting below 100-200 mile cell sizes is unlikely. The geometry of such situations will be less sensitive than the 50 mile case illustrated below, and greater spacing thus could be easily accommodated.

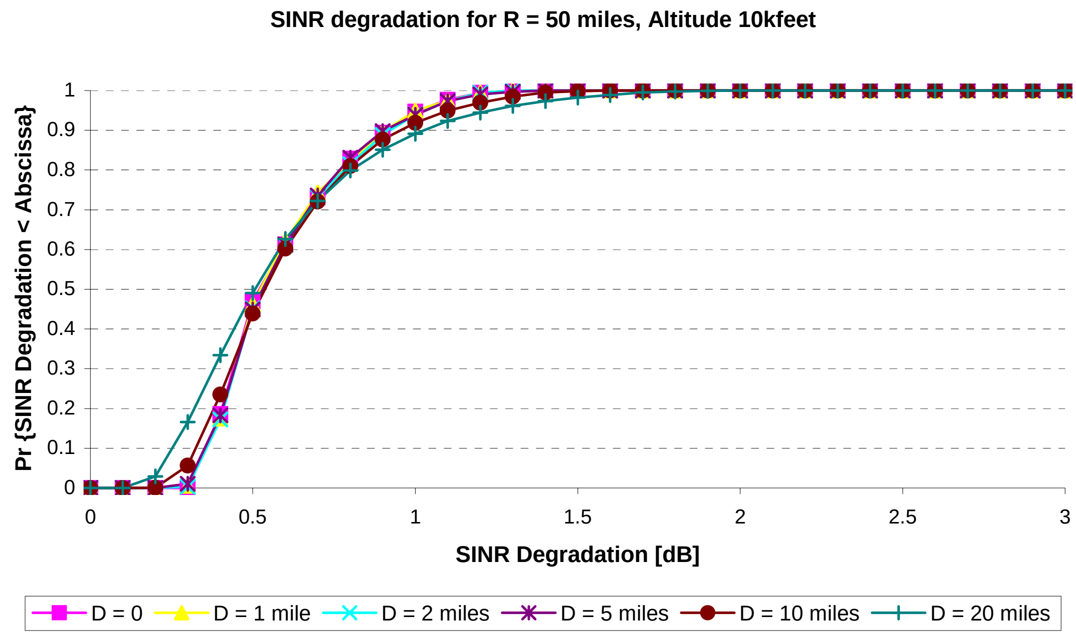


**Figure 12.** SINR degradation as a function of spacing between System 1 and System 2 cell sites, 50 mile cell radius

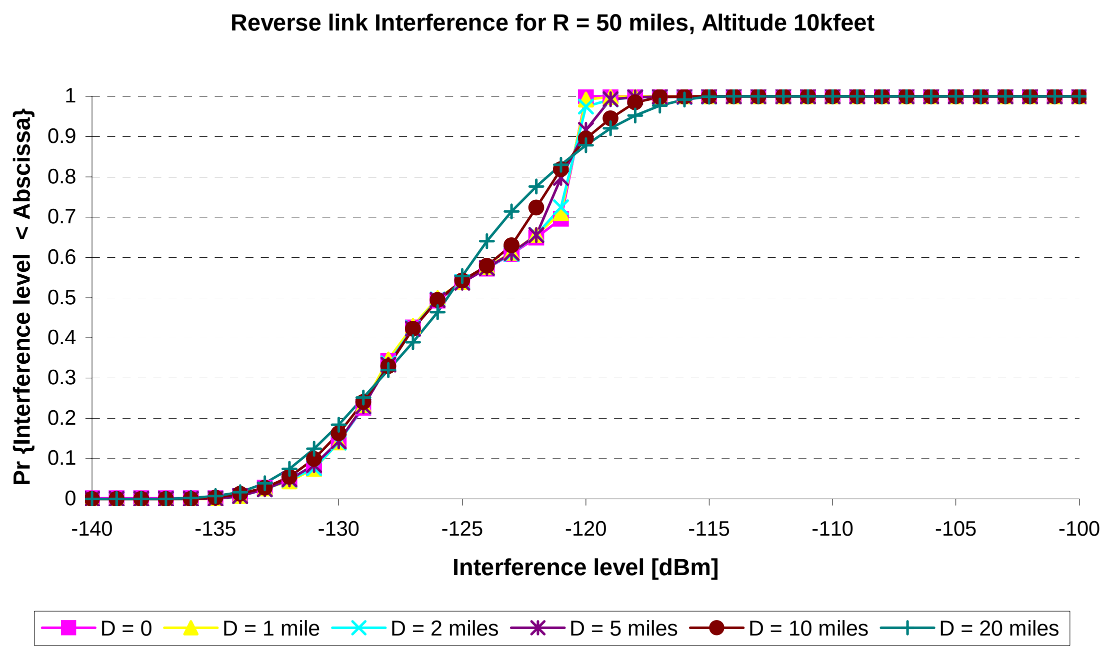


**Figure 13.** Reverse link interference as a function of spacing between System 1 and System 2 cell sites, 50 mile cell radius

## 4.4. *Inter-system site spacing for airport sites*

The impact of intersystem site spacing for airport sites is most evident in the area near the airport, where the differences in path geometries from aircraft to two non-collocated cell sites is greatest.  The area 20 miles around the airport was evaluated to determine the impact of intersystem interference on the forward link data throughput, as shown in Figure 14 below.

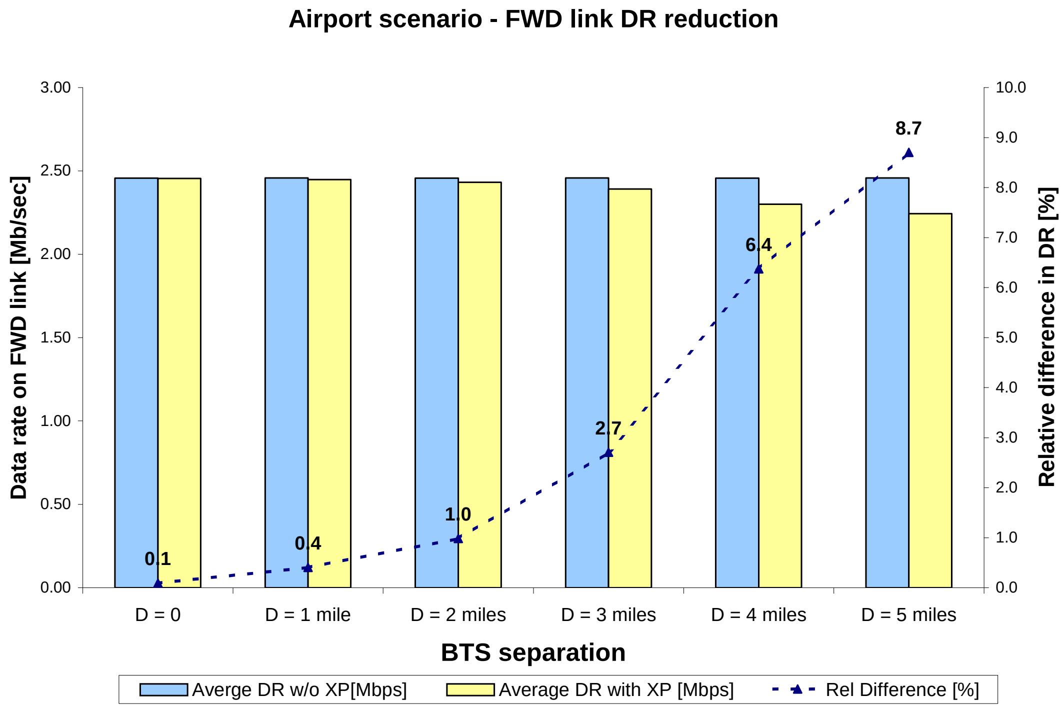


**Figure 14.** Forward link data rate reduction as a function of intersystem spacing of airport cell sites

Spacing of 2 miles between cell sites has minimal impact on the forward link, although, once again, this is a “soft” constraint that could easily be relaxed where warranted by other considerations.

The impact of cell spacing on the reverse link was also evaluated over the same range of cell separations, and the results are shown in Figure 15 below.  It is apparent that, even with the system loaded to the 75% pole point, the reverse link interference levels will be well below the noise floor for 2 mile spacing of cell sites.

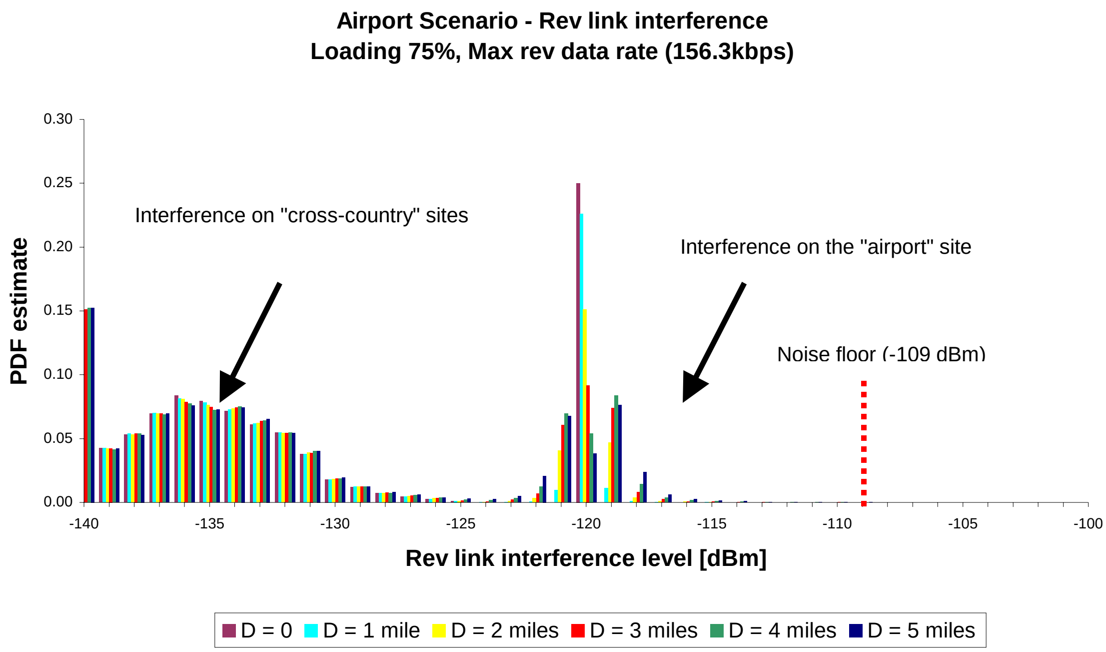


**Figure 15.** Reverse link interference as a function of intersystem spacing of airport cell sites

## 4.5. *Cross-country split cells*

As discussed in section 2.1, the geometry of cells in the cross-country scenario can utilize antenna discrimination in the vertical pattern to compensate for the distance-related near-far effect. A value of 20 dB discrimination over the range of 15° above the horizon to 90° above the horizon significantly limits the near far effect, and will permit "split" cell sites to be added to a network without requiring that a site from the second system be built nearby. Figures 16 and 17 below reflect a situation in which a System 1 split site is located midway between primary locations, each with System 1 and System 2 cells with 100 mile radius. A System 2 site has not been constructed near the System 1 split cell.

Since the split cell is halfway between the original sites, near-far issues are maximized. The impact on System 2 is roughly 10-12% on forward link capacity and the low levels of interference on the reverse link indicate that there will be effectively no impact. In many cases, this impact will be tolerable, and it will be significantly reduced when spectrum offset is implemented. Further refinement of the antenna mask requirements may also further reduce the intersystem impacts.

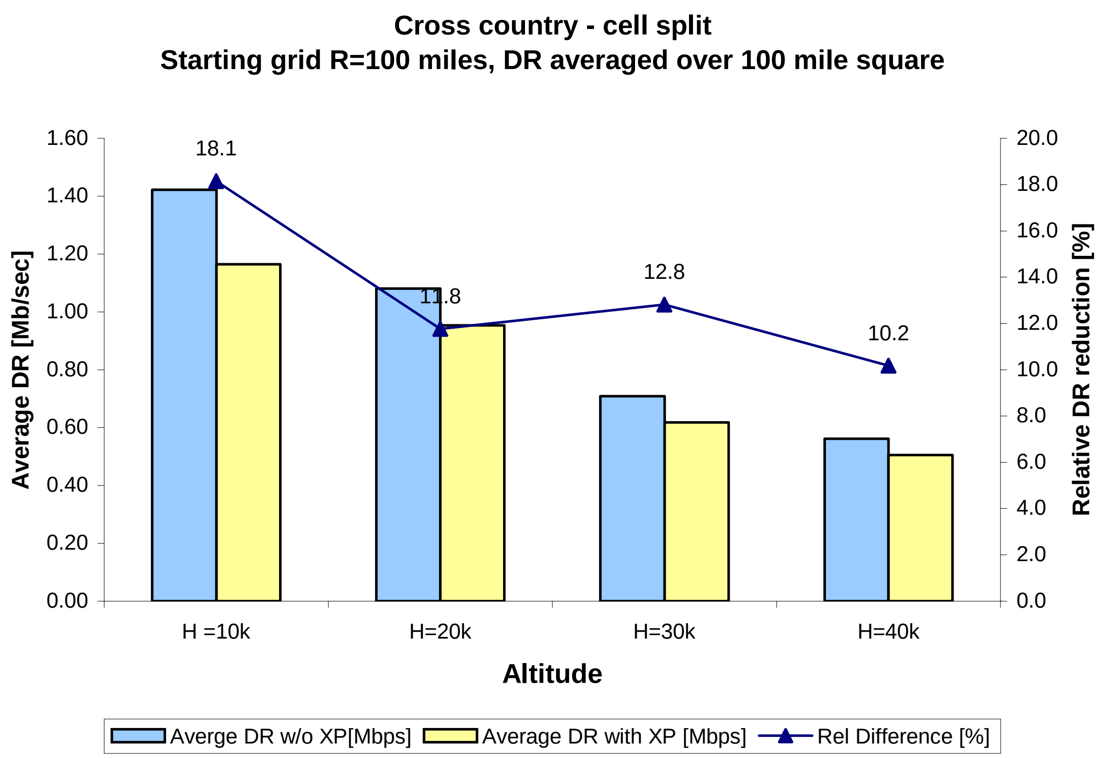


**Figure 16.** Forward link impact for cell split on only one system

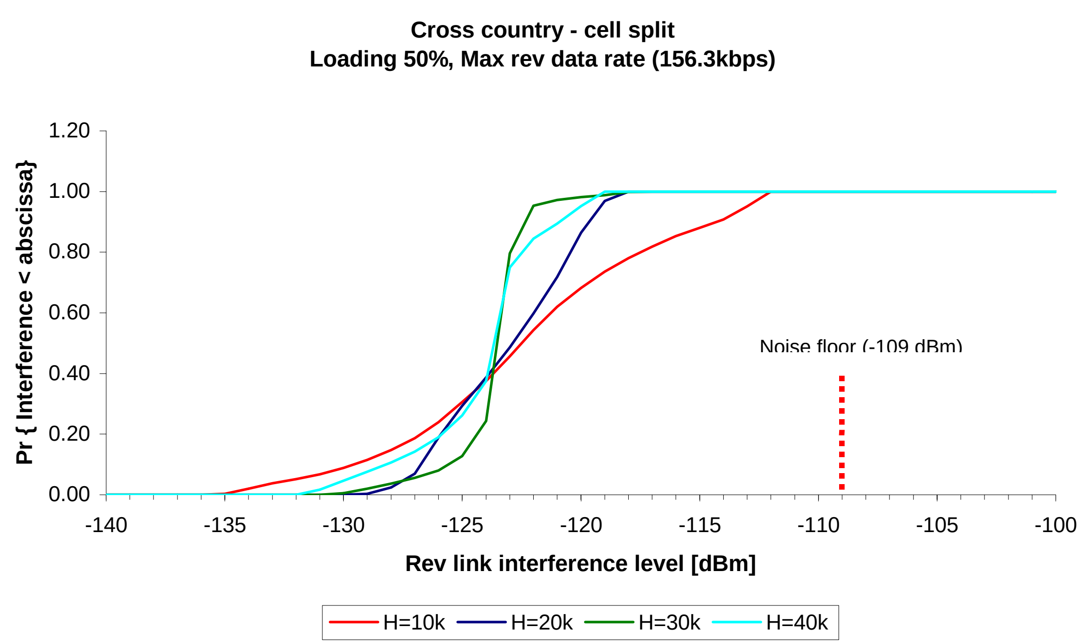


**Figure 17.** Forward link impact for cell split on only one system

### 4.6. *Effect of aircraft maneuvers on cross-polarization discrimination*

When cross-polarized antennas are positioned at exactly 90°, the isolation between them is theoretically infinite. For antennas which have a fixed polarization relative to the aircraft body, there will be some loss of polarization isolation when the aircraft pitches (*i.e.*, climbs or descends) or when the aircraft rolls (*i.e.*, banks in a turn). Figure 18 below indicates the amount of polarization discrimination as a function of aircraft pitch/roll maneuvers.

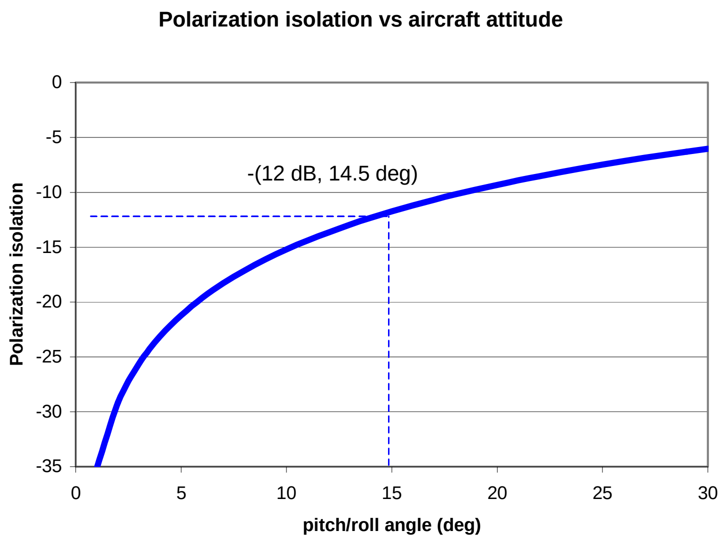


**Figure 18.** Effects of aircraft maneuvers on cross polarization isolation

Boeing recently analyzed statistics for a sample of aircraft to assess the potential impact of aircraft maneuvers. While the flights were above an altitude of 10,000', they were considered to be en route (or cross-country), and when they were below 10,000' they were considered to be in the vicinity of airports.

The analysis showed that the aircraft flew with a "nose up" attitude of 3° most of the time, with limits of –1° and 13°. Presuming that antennas would be mounted on the aircraft to compensate for the normal 3° pitch, the range of antenna angles caused by pitch changes would be from –4° to 10°, well inside the limits that would cause isolation less than 12 dB. Figure 19 shows the probability distribution function for pitch angles measured.

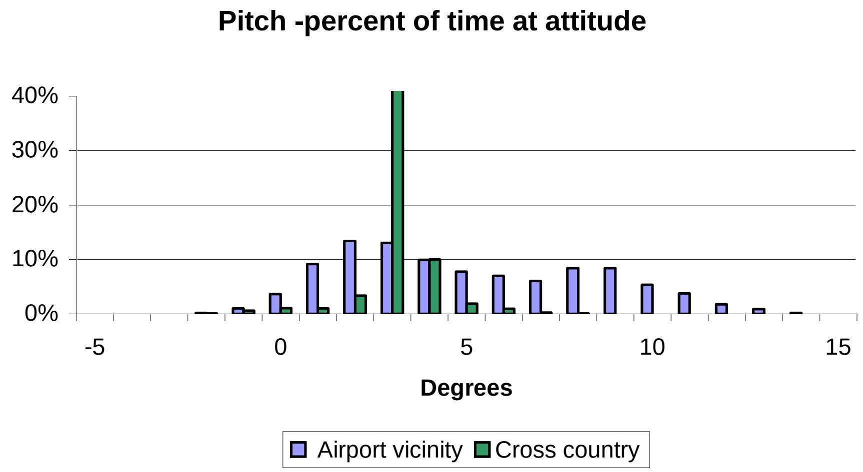


**Figure 19.** Pitch angles of aircraft

Roll angles have a greater range than pitch angles. Figure 20 shows the percentage of time that a roll angle is exceeded. In cross-country situations, the roll angle is 0° 92% of the time, with roll angles of 14° or less 99.99% of the time. In the vicinity of airports, roll angles are more than 14° only 3% of the time, and are less than 20° (corresponding to 9.3 dB of cross-polarization isolation) 98.8% of the time. Considering that perhaps 20% of an aircraft's flight time is in the vicinity of airports, and that the safety regulations will require that most or all passenger equipment be stowed during takeoff and landing, the overall impact of aircraft maneuvers on communications capacity will be negligible.

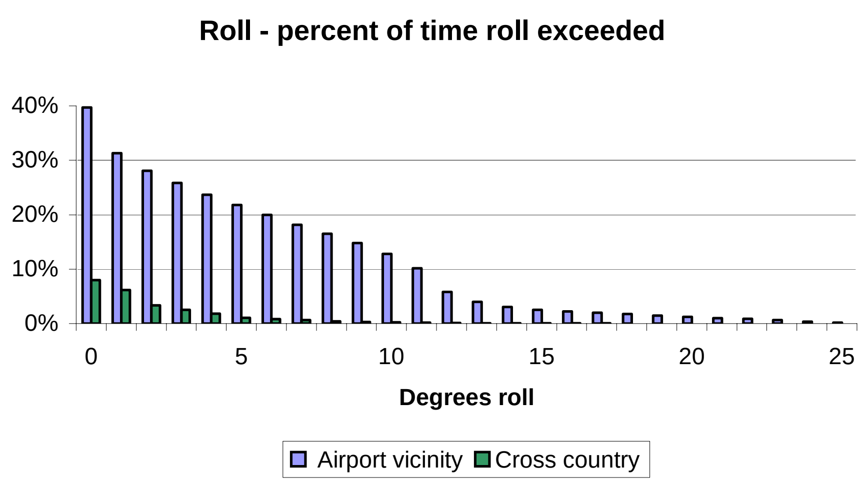


**Figure 20.** Roll angles of aircraft

To consider the potential impact to system performance, consider an extreme case – a 30-degree banking maneuver near an airport for an aircraft operating under one of the systems (*e.g.*, V-pol system). This deviation would amount to an increased path loss of 1.25 dB on the V-pol system (*i.e.*, -20*log(cos(30))). The aircraft's transmitted power will increase 1.25 dB to compensate, but will have no impact on the system loading of the V-pol system as the received power at the base station will be unchanged.

To consider the worst case impact on the H-pol system, we recognize that the 30-degree deviation in the V-pol aircraft reduces the xpd to 6 dB (-20*log(sin(30))). If both systems are assumed to carry almost the same traffic (almost the same noise floor and noise rise in normal operation), the contribution to the noise floor of the H-pol system from 1.25 dB extra aircraft transmit power in the V-pol system and the polarization reduction will still be 4.75 dB below the H-pol system's noise floor. Thus, there will be no impact to the V-pol system reverse link operation.

A similar analysis on the forward link would suggest that an xpd of 6 dB still exists for aircraft operating with a 30-degree deviation providing broadband data rates even in the worst-case bank maneuver of an aircraft. In the eventual partially overlapped spectrum configuration, an additional 2.2 dB of isolation will be available.

## 5. Summary

This document outlines a two licensee system deployment in the ATG spectrum. The plan accommodates two broadband systems operating in cross-polarized (XP) mode and provides a graceful means for phasing out of the legacy narrowband system. The plan is characterized by simple spectrum sharing rules and allows for interference-free operation in virtually all cases of practical interest. Simulations are used to determine levels of possible cross-system interference between the systems. The simulations confirm that the inter-system interference levels are negligible even with a straightforward deployment approach that does not utilize more advanced interference rejection techniques such as switched-beam or smart antennas, filtering or interference rejection techniques.

## 6. References


1. I. Kostanic, "Evaluation of the ATG Spectum Migration Concept," March 10, 2004, AirCell report to the FCC, WT Docket 03-103.
2. I. Kostanic, "Evaluation of the ATG Spectrum Migration Concept (Part 2)," June 29, 2004, AirCell report to FCC, WT Docket 03-103.
3. Ex Parte Presentation by Qualcomm, WT Docket 03-103, September 3, 2004.
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