Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of:	)	
AERONAUTICAL RADIO INC.	)	File No. SES-LIC-20030910-01261,
	)	Call Sign E030205
Application for Blanket Authority to Operate Aboard Aircraft Up To 1000 Technically-Identical Transmit and Receive Mobile Earth Stations in the 11.7-12.2 and 14.0-14.5 GHz Frequency Bands	)	

FURTHER COMMENTS OF THE BOEING COMPANY

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SUMMARY

The Boeing Company ("Boeing") hereby submits these further comments addressing both new and continuing questions regarding the technical aspects of the Ku-band Aeronautical Mobile-Satellite System ("AMSS") proposal of Aeronautical Radio, Inc. ("ARINC") – the SKYLink system. Boeing has carefully designed and implemented its licensed Ku-band AMSS system – the Connexion by Boeing^{SM} ("Connexion") system – in accordance with domestic and international requirements necessary to protect primary Ku-band Fixed-Satellite Service ("FSS") operations and other co-frequency services in the 14.0-14.5 GHz band. Boeing urges the Commission to ensure that the SKYLink system also operates in accordance these requirements, and that it will protect other users of the Ku-band to the same rigorous standards imposed on the Connexion system.

ARINC confirms, however, in its most recent submission that the SKYLink system is designed to comply for only 99% of the time with the applicable AMSS off-axis e.i.r.p. limits. In contrast, the Connexion system is designed to ensure that the aggregate e.i.r.p. of its aircraft earth stations ("AES") do not exceed the required levels, including a 1 dB margin, with a confidence level of 99.99% under worst-case conditions. Authorizing the SKYLink system to operate with a substantially higher level of potential interference into primary Ku-band FSS networks would afford ARINC an unwarranted competitive advantage over properly designed AMSS systems, and could result in Boeing being mistakenly blamed for an interference event or being the victim of harmful interference caused by the SKYLink system.

The SKYLink system also does not satisfy the "essential requirement" of positive control for Ku-band AMSS operations -- a requirement that was discussed throughout the ITU-R study group process in developing Recommendation ITU-R M. 1643 and was central to WRC-03's

adoption of the secondary AMSS allocation in the 14.0-14.5 GHz band. The positive control requirement also has been imposed by the Commission in authorizing all secondary Mobile-Satellite Service ("MSS") operations in the band, including Connexion's AMSS operations and the OmniTRACS Land Mobile-Satellite Service ("LMSS") operations.

To the extent that ARINC seeks to establish a less restrictive confidence level to protect primary Ku-band FSS operations under all conditions and to employ something other than positive control of AES transmissions, ARINC should do so in the context of the upcoming AMSS rulemaking proceeding. In the interim, however, the Commission should refrain from adopting on an ad hoc basis less stringent requirements that could have significant competitive and interference consequences.

The Commission also should require ARINC to provide complete responses to all unresolved technical questions before any action is taken on the SKYLink application. These questions generally relate to the ability of the SKYLink system to protect primary Ku-band FSS operations and the actual level of protection afforded by the SKYLink system, and thus cannot simply be ignored because ARINC has failed to address them. If the Commission ultimately grants the SKYLink application, it should require ARINC to submit a report verifying its ability to comply with all AMSS license conditions prior to commencing commercial operations.

Finally, the Commission should designate the SKYLink application proceeding as "permit-but-disclose" under the Commission's *ex parte* rules. Such a status would enable the parties to address fully the complex technical issues and continuing questions associated with the SKYLink application, and will afford the Commission with a more complete record upon which to evaluate ARINC's AMSS proposal.

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FURTHER COMMENTS OF THE BOEING COMPANY

The Boeing Company ("Boeing"), by its attorneys, hereby submits these further comments addressing the Response of Aeronautical Radio Inc. ("ARINC") in the above-captioned application proceeding.[1] These further comments highlight both new and continuing questions regarding the technical aspects of the SKYLink proposal, as supplemented by the *ARINC Response*. Although the *ARINC Response* contains additional information on the SKYLink Ku-band aeronautical mobile-satellite service ("AMSS") system not included in the original application,[2] ARINC still has not provided sufficient details regarding its proposed system to demonstrate that it complies fully with Recommendation ITU-R M.1643 or adequately protects co-frequency users of the Ku-band.

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[1] *See* Response of ARINC Incorporated, File No. SES-LIC-20030910-01261, Call Sign E030205 (filed Nov. 28, 2003) ("*ARINC Response*"). To the extent required, Boeing hereby requests leave to file these further comments primarily to address the new information submitted in the *ARINC Response*. *See* The Boeing Company's Motion For Leave to File Further Comments, File No. SES-LIC-20030910-01261, Call Sign E030205 (filed Dec. 18, 2003).

[2] *See* Aeronautical Radio Inc., Application for Blanket Authority to Operate Aboard Aircraft Up To 1000 Technically-Identical Transmit and Receive Mobile Earth Stations in the 11.7-12.2 and 14.0-14.5 GHz Frequency Bands, File No. SES-LIC-20030910-01261, Call Sign E030205 (Sept. 2, 2003) ("*ARINC Application*").

I. INTRODUCTION

Boeing files these further comments to address additional information submitted by ARINC in connection with its SKYLink AMSS proposal. Boeing's comments on ARINC's proposed system, which are technical in nature and relate solely to the SKYLink system's interference characteristics, are driven by concerns of regulatory parity and protection of Boeing's own licensed AMSS operations. To obtain international and domestic approval for its AMSS system, Boeing designed the Connexion by Boeing[SM] ("Connexion") system to comply with a rigorous set of requirements to protect co-frequency systems. These requirements, which include meeting applicable off-axis e.i.r.p. values with a 99.99% confidence level (including all potential errors that affect off-axis e.i.r.p. under worst case conditions) and positive control of transmitting aircraft earth stations ("AES"), constitute a baseline for Ku-band AMSS systems that has been accepted by the international community and the Commission. There is no evidence in the record of this proceeding that would warrant relaxation of these requirements, particularly since the Ku-band AMSS allocation and AMSS technical recommendation recently adopted by the International Telecommunication Union ("ITU") are based on these essential AMSS system characteristics.

In addition, Boeing seeks to ensure that all Ku-band AMSS systems – including the SKYLink system – are held to the same rigorous standards as the Connexion system because Boeing could be mistakenly blamed for interference caused by ARINC's proposed AMSS operations and be required to cease operations;[3] and because Boeing itself could be the victim of harmful interference from ARINC's proposed operations since it uses Ku-band FSS satellite

[3] Boeing's AMSS authorization requires it to "immediately cease mobile satellite operations upon notification of… harmful interference resulting from its operations." *The Boeing Company,* Order and Authorization, 16 FCC Rcd. 22645 (Int'l Bur./OET 2001) ("*Connexion Transmit/Receive Order*") at ¶ 19(a).

capacity to provide the Connexion service. The operational uncertainties and interference concerns raised in Boeing's original comments[4] and in these further comments are particularly unsettling because SKYLink's serving satellite -- the AMC-1 satellite at 103° W.L. -- is only two degrees away from the AMC-4 satellite at 101° W.L. used by the Connexion system. Thus, the risks of Boeing being erroneously blamed for harmful interference caused by the SKYLink system or being the victim of such interference are real and substantial.[5]

ARINC seeks to minimize these and other problems raised by Boeing by characterizing the *Boeing Comments* as a "desperate patchwork of concerns and questions."[6] However, the technical concerns and other issues raised by Boeing relate directly to the SKYLink system's lack of demonstrated ability to satisfy established AMSS requirements; and are based on Boeing's first-hand knowledge of the evolution and adoption of Recommendation ITU-R M.1643 and the worldwide secondary AMSS allocation, and its extensive experience in developing and operating the Connexion system. Boeing's "concerns and questions" are necessarily directed at discrete technical issues because the SKYLink application contains material mistakes, omissions and uncertainties so as to defy comprehensive analysis; and because appropriate implementation of Ku-band AMSS systems and services must account for the many complex technical issues analyzed in detail over the past several years in the context of international adoption of Recommendation ITU-R M.1643 and the associated AMSS allocation

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[4] *See* Comments of The Boeing Company, File No. SES-LIC-20030910-01261 (filed Nov. 14, 2003) ("*Boeing Comments*").

[5] The difficulty an FSS operator would have identifying an interfering AMSS terminal was raised by PanAmSat in the Boeing AMSS licensing proceeding. *See* Comments of PanAmSat Corporation, File No. SES-LIC-20001204-02300 (filed Mar. 23, 2001) at 3. As a result of these and other comments, Boeing agreed to operate its system with positive control and assure protection to a 99.99% level, as set forth in its application, as amended.

[6] *ARINC Response* at 3.

and Commission licensing of the Connexion system. Although ARINC may not appreciate the adverse consequences of failing to properly account for these issues in the design and operation of its proposed AMSS system, the Commission (which has carefully examined such technical issues in its prior AMSS licensing proceedings) cannot ignore them.

To the extent that ARINC seeks to alter accepted domestic and international requirements for AMSS operations, it should do so in the context of the impending AMSS rulemaking proceeding. In the meantime, the Commission should enforce its existing spectrum sharing regime and maintain a level regulatory playing field. Additional AMSS service providers must therefore be held to the same rigorous requirements imposed by the Commission on the Connexion system to protect fully other co-frequency users of the spectrum.

II. THE SKYLINK SYSTEM MUST PROTECT KU-BAND FSS NETWORKS TO THE SAME LEVEL AS BOEING'S LICENSED AMSS SYSTEM

The *ARINC Application* suggests that the SKYLink system controls potential interference to a confidence level of 99.999%, but the Technical Description associated with the application includes only a 99% figure. Boeing pointed out this discrepancy in its initial comments and noted that "[t]he relationship between these two claims is not entirely clear."[7] ARINC provides only a vague, one-sentence response to this point, suggesting that the percentage variation "is due to the inclusion of two values -- the expected case and the threshold for exercising positive control...."[8] The true import of ARINC's response is revealed only by a further examination of the additional explanation contained in its latest SKYLink Technical Exhibit.[9]

[7] *See Boeing Comments* at 12.

[8] *See ARINC Response* at 10. Of course, ARINC incorrectly uses the term "positive control" in this instance.

[9] *See id.* at SKYLink Technical Exhibit.

ARINC now confirms that the SKYLink system is designed to comply with the applicable off-axis e.i.r.p. limits for only 99% of the time.[10] The 99.999% value apparently assumed only "normal" or "expected" traffic rather than worst case or peak traffic. In other words, the SKYLink system is designed to permit the aggregate e.i.r.p. of transmitting AESs to exceed the levels imposed by the Commission for the protection of primary Ku-band FSS networks for up to 1% of the time.

In contrast, the Connexion system is designed to ensure that the aggregate e.i.r.p. of transmitting AESs do not exceed the required levels, including a 1 dB margin, with a confidence level of 99.99% under worst-case conditions including all potential errors identified in the ITU-R study group process and Boeing's FCC licensing proceeding (*e.g.*, pointing error, power control error, etc.). Even without further examination, the SKYLink system is at least 100 times more likely to exceed the off-axis e.i.r.p. limits imposed on AMSS systems to protect primary Ku-band FSS operations than the licensed Connexion system. However, as discussed in Section IV, *infra*, this disparity in protection levels is far greater given the additional technical shortcomings in the SKYLink proposal.[11]

The Commission has authorized Boeing to operate in the 14.0-14.5 GHz band by controlling off-axis e.i.r.p. with a confidence level of 99.99% under all conditions.[12] Moreover,

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[10] *See* SKYLink Technical Exhibit at 2 ("The SKYLink NMS actively manages the probability of exceeding off-axis e.i.r.p. density to be no greater than 1%").

[11] For example, ARINC claims that it will meet the applicable off-axis e.i.r.p. limits with a 99% probability, minus a 1 dB margin. However, the 1 dB margin is attributed to AES pointing error (a factor that must be included in off-axis e.i.r.p. control, not margin; *see Connexion Transmit-Receive Order* at ¶19(h)(5.1)) -- thus, there is actually no margin at all. Furthermore, the off-axis e.i.r.p. of the forward link, uplink calibration error and other factors appear to be neglected in the ARINC calculations.

[12] *See Connexion Transmit/Receive Order* at ¶ 20 (Boeing shall operate its "transmit and receive AMSS stations in the 14.0-14.5 GHz and 11.7-12.2 GHz bands, consistent with the

the FSS protection provisions contained in Recommendation ITU-R M.1643 are based on an AMSS system meeting the applicable limits 99.99% of the time under worst-case conditions.[13] Similarly, the 2003 World Radiocommunication Conference ("WRC-03") decision to allocate the 14.0-14.5 GHz band for AMSS services was based on a protection level of 99.99%.[14] Thus, both the Commission and the international community have concluded that a properly designed AMSS system should control off-axis e.i.r.p. to the applicable limits with a confidence level of 99.99% under all conditions to protect adequately primary Ku-band FSS networks. There is nothing in the development of Recommendation ITU-R M.1643 or the Commission's licensing proceeding leading to the authorization of the Connexion system's transmit/receive operations to indicate that a less stringent requirement is acceptable.

To the extent that ARINC seeks to reduce dramatically the level of protection afforded to other authorized users of the 14.0-14.5 GHz band accepted by the international community and imposed by the Commission in authorizing the Connexion system, it should do so in the context

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technical parameters specified in its application and supporting documents, and the conditions set forth in this Order").

[13] *See* Document 4A/129-E at 3 ("[t]he design limit for the aggregate off-axis e.i.r.p. density [has] . . . a 99.99% confidence. A 1 dB unallocated system margin is subtracted from this. This margin is intended to account for unknown effects and failures in the system."); 6 ("the aggregate e.i.r.p. spectral density envelope is calculated to a 99.99% confidence level using the known error characteristics of the system. . . . A 1 dB unallocated system margin is added."); and 19 ("more than 100 000 trials which are used to determine the actual 99.99% e.i.r.p. envelope. This envelope can then be compared to the design limit minus a 1 dB unallocated margin to determine the success or failure of the algorithm used by the NOC.")

[14] *See* Conference Preparatory Meeting Report to the 2003 World Radiocommunication Conference (WRC-03), § 2.4.1.2.1 at 59 ("CPM Report") ("The compatibility study with the FSS . . . . determined that the NCMC could control the aggregate off-axis e.i.r.p. levels to those of Recommendation ITU-R S.728-1 for both 2° and 3° GSO satellite spacing to a 99.99% confidence level. This analysis verified that it was feasible to control the aggregate off-axis e.i.r.p. density levels from an AMSS network to be no greater than that of coordinated VSATs, as characterized in Recommendation ITU-R S.728-1.")

of the AMSS rulemaking proceeding that will soon be initiated by the Commission.[15] In the interim, however, the Commission should refrain from adopting less stringent protection requirements on an ad hoc basis in the context of ARINC's AMSS proposal that could have significant competitive and interference consequences.

III. THE SKYLINK SYSTEM DOES NOT SATISFY THE "ESSENTIAL REQUIREMENT" OF POSITIVE CONTROL FOR KU-BAND AMSS OPERATIONS

Boeing has worked closely with the Commission, other U.S. government departments and interested parties over the last several years to develop the international regulatory framework to permit AMSS operations worldwide in the Ku-band. Indeed, Boeing was the principal author of technical studies and U.S. inputs into the ITU-R study group process addressing Ku-band AMSS technical and regulatory matters. These efforts began in 2000 with the adoption of Resolution 216 (Rev. WRC-2000), which proposed technical studies to consider whether the secondary Mobile-Satellite Service allocation in the 14.0-14.5 GHz band (Earth-to-space) that included Maritime Mobile-Satellite and Land Mobile-Satellite Services, but expressly excluded the Aeronautical Mobile-Satellite Service, could be broadened on the basis of the results of these studies to include AMSS. These efforts culminated in the adoption of Recommendation ITU-R M.1643 on the "Technical and Operational Requirements for Aircraft Earth Stations of Aeronautical Mobile-Satellite Service Including Those Using Fixed-Satellite Service Network Transponders in the Band 14-14.5 GHz (Earth-to-space)" by the 2003 Radiocommunication Assembly, and the secondary AMSS allocation in the 14.0-14.5 GHz band

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[15] *See* Amendment of Parts 2 and 25 of the Commission's Rules To Allocate Spectrum in the 14-14.5 GHz Band to the Aeronautical Mobile-Satellite Service ("AMSS") and To Adopt Licensing Rules for AMSS Operations in the Ku-Band, RM No. 10800, Petition for Rulemaking filed by The Boeing Company (July 21, 2003); *see also Public Notice,* Consumer & Governmental Affairs Bureau, Reference Information Center, Petition for Rulemaking Filed, Report No. 2632 (Oct. 2, 2003).

by WRC-03.[16]

While Boeing and the United States were pursuing expansion of the secondary MSS allocation in the 14.0-14.5 GHz band at the ITU, Boeing was also seeking domestic authorization for its proposed AMSS system on a non-conforming basis in advance of action on the allocation change. Boeing and the Commission looked to the licensing conditions of the other system operating in the secondary MSS allocation in the band, OmniTRACS, in developing appropriate requirements for Ku-band AMSS operations. A critical element of the Commission's decision to authorize the secondary LMSS services in the 14.0-14.5 GHz band was positive control of transmissions to protect primary FSS systems from harmful interference.

In its initial comments, Boeing noted that the SKYLink system's contention protocol scheme is not consistent with Commission precedent and Recommendation ITU-R M.1643. In addition to the Commission's *OmniTRACS* decision and the conditions in Boeing's AMSS license, Boeing cited the provisions of Recommendation ITU-R M.1643 which require positive control of AESs transmitting in the 14.0-14.5 GHz band to protect adjacent FSS satellites from harmful interference.[17]

Although Recommendation ITU-R M.1643 does not mandate a particular system design, it does set forth a number of "essential requirements" for the design and operation of Ku-band AMSS systems. At Annex 1 (Part A, Section 4), the Recommendation provides: "AES should be subject to the *monitoring and control by an NCMC or equivalent facility*. AES must be able to

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[16] *See* Recommendation ITU-R M.1643; *see also* Provisional Final Acts of WRC-03, Article 5 (adopting an international AMSS allocation by removing the exclusion against aeronautical mobile-satellite in the existing secondary Mobile-Satellite Service (Earth-to-space) allocation at 14.0-14.5 GHz).

[17] *See Boeing Comments* at 5-6.

receive at least 'enable transmission' and 'disable transmission' commands from the NCMC."[18] The use of the terms "monitoring" and "control" denote proactive and ongoing activity associated with positive control of AESs transmitting in the 14.0-14.5 GHz band. Moreover, the underlying technical studies upon which the Recommendation is based confirm that positive control of AES transmissions is an "essential requirement" of Ku-band AMSS operations necessary to protect primary Ku-band FSS networks.

Studies of sharing between AMSS and FSS networks began in ITU-R Working Party 4A in September 2000 with the introduction of Document 4A/28 submitted by the United States.[19] Among other things, Section 3 of that document specifically cites licensed Land Mobile-Satellite Service ("LMSS") and Maritime Mobile-Satellite Service ("MMSS") systems (*i.e.*, OmniTRACS and its domestic maritime distributor Boatracs) as the precedent for proposed AMSS operations in the Ku-band. The last paragraph of Section 3 provides:

> A key element of the existing LMSS and MMSS systems that allows them to control their aggregate emissions is network control. Network control ensures that the sum of all of the terminals transmitting simultaneously at the same frequency and pointing to the same satellite does not exceed the desired EIRP density level by *managing the entry of new terminals in to the network and the power settings of terminals so that the operation will not cause harmful interference to the primary service. Existing LMSS and MMSS system use a transmit-on-command system.* This assures that the antenna is properly pointed when transmitting, since it will not receive a command if the system is not pointing towards the correct satellite. . . . Any feasible AMSS system will have to include network control appropriate for transmitters in an airborne environment.[20]

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[18] *See* Recommendation ITU-R M.1643 at Annex 1 (Part A, Section 4) (emphasis added).

[19] *See* Working Document on Protection of GSO FSS Networks from Harmful Interference Due to a Aeronautical Mobile Satellite Service (AMSS) System in the Band 14-14.5 GHz (United States), Doc. 4A/28-E (Sept. 14, 2000) (attached as Exhibit 1).

[20] *See id.* at 3 (emphasis added).

Thus, not only is the *OmniTRACS* precedent of positive control for transmitting LMSS terminals relevant, but it was the foundation upon which the AMSS technical studies at the ITU-R were based.

The ITU-R studies regarding AMSS operations were continued in Working Party 4A with Document 4A/129 submitted by the United States.[21] This is the primary technical study regarding AMSS/FSS sharing requirements, and again underscores the importance of positive control for AMSS operations. Document 4A/129 states in pertinent part that:

> . . . extensive fault management both on the ground and in the airborne terminals assures that no transmission will occur from any airborne terminal without positive control from the ground. . . . [22]
>
> Transmissions from the aircraft are under positive control of the NOC. This control includes airborne terminal entry into the network, authorization of transmission frequencies, authorizations to change the transmit power/data rate, and control of the authorized transmit power level . . . .[23]
>
> Positive control of airborne terminals is essential to maintaining control of aggregate emissions. Features are included in the system design to ensure that no transmissions take place from an aircraft unless it is under positive control.[24]

Thus, in the context of further ITU-R study, positive control of AMSS terminals was considered "*essential* to maintaining control of aggregate emissions" for the system on which the study was based.[25]

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[21] *See* Working Document Towards Draft CPM Text In Response To Resolution 216 (WRC-2000): System Characteristics and GSO FSS Sharing Study for a Proposed AMSS System in the 14.0-14.5 GHz Band (United States), Doc. 4A/129-E (Apr. 11, 2001) (attached as Exhibit 2).

[22] *See id.* at 2.

[23] *See id.* at 5.

[24] *See id.* at 7.

[25] *See id.* (emphasis added).

The technical study contained in Document 4A/129 lead directly to the text of the CPM Report for WRC-03. On this point, Section 2.4.1.2.1 of the CPM Report provides:

> One central factor in the design of the planned AMSS network used for the FSS compatibility studies, is that the 14 GHz transmissions from the aircraft earth stations (AES) would be received by space station facilities that were coordinated with adjacent satellites. *A second central design factor of the AMSS system is that the individual AES transmissions would be under the positive control of a network control and monitoring centre (NCMC),* which would limit the aggregate off-axis, co-frequency, e.i.r.p. levels from multiple AES at adjacent satellites to (or below) those levels that have been accepted by other satellites, including, *inter alia*, effects of antenna pattern variations and pointing stability.[26]

The CPM Report goes on to state that:

> AMSS networks will need *rigorous protocols to control the operation of AES to be within the agreed limits*. These controls include: *entry* of AES into the network; *authorization* for the AES to transmit; *authorization* to change transmit power/data rates and frequency assignment; and the ability to terminate AES transmissions. An NCMC *must manage AES transmission levels* within ranges both on an individual and on an aggregate (per transponder) basis.[27]

The foregoing discussion in the CPM Report confirms that positive control and active management of AES transmissions were central to WRC-03's adoption of the AMSS allocation in the 14.0-14.5 GHz band.

The positive control requirement discussed throughout the ITU-R study group process in developing Recommendation ITU-R M.1643, which was based on the requirements previously imposed by the Commission in authorizing LMSS and MMSS operations in the 14.0-14.5 GHz band, was also included in the ordering clauses of the Connexion authorization using the same language contained in the Working Party 4A document that ultimately became part of the ITU-R Recommendation.[28] Thus, the Commission itself used the anticipated language of

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[26] *See* CPM Report, § 2.4.1.2.1 at 58 (emphasis added).

[27] *See id.* at 58-59 (emphasis added).

[28] *See Connexion Transmit/Receive Order* at ¶ 19(h)(3) ("AMSS mobile terminals [shall

Recommendation ITU-R M.1643 to describe and authorize an AMSS system with positive control of AES transmissions; any suggestion that Boeing's authorization does not require positive control ignores the fact that the Commission authorized the Connexion system to operate only in the manner described in the underlying application.[29]

As with the requirement for Ku-band AMSS systems to meet applicable off-axis e.i.r.p. levels for 99.99% of the time under all conditions, to the extent that ARINC seeks to modify or eliminate the requirement of positive control of AES transmissions accepted by the international community and imposed by the Commission in connection with all secondary MSS uses of the 14.0-14.5 GHz band (including for AMSS, LMSS and MMSS operations), ARINC should do so in the upcoming AMSS rulemaking proceeding.

IV. OTHER SIGNIFICANT TECHNICAL QUESTIONS REMAIN UNANSWERED CONCERNING THE SKYLINK PROPOSAL

In its initial comments, Boeing identified material and substantial questions with respect to the proposed SKYLink system design that still have not been adequately addressed by ARINC. In many respects, these were the same questions asked of Boeing and answered successfully during its licensing proceeding. These issues generally relate to the ability of the SKYLink system to protect primary Ku-band FSS operations and the actual level of protection afforded by the SKYLink system, and thus cannot simply be ignored because ARINC has failed to address them. The Commission should require ARINC to provide complete responses to all unresolved technical questions before any action is taken on the SKYLink application.

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be] monitored and controlled by a ground-based Network Control and Monitoring Center ("NCMC") or equivalent facility"); ¶ 19(h)(4.1) (AMSS mobile terminals shall "be able to receive at least 'enable transmission' and 'disable transmission' commands from the NCMC").

[29] *See id.*, ¶ 20 (Boeing shall operate its "transmit and receive AMSS stations in the 14.0-14.5 GHz and 11.7-12.2 GHz bands, consistent with the technical parameters specified in its application and supporting documents, and the conditions set forth in this Order").

A. AES Log-in and Burst Mode Issues

In its initial comments, Boeing noted that the SKYLink system's login protocol allows an AES to transmit a login burst at any time and with increasing power levels once it receives the forward link without authorization of the Network Management System ("NMS"), and that it is not clear how the off-axis e.i.r.p. of the AESs attempting to login is treated in the overall aggregate power determination for the SKYLink system.[30] In response, ARINC indicates that there is a maximum number of permissible attempts that an AES can make before it must stop for a "quiet period" and a maximum power amplitude increase permitted during the log-in process.[31] However, the maximum number of log-in attempts, maximum power amplitude increase, and length of the quiet period are not revealed in its application or other submissions. ARINC should provide this data in order to better analyze the potential for interference.

In addition, Boeing noted that since logged-in AESs transmit user data in burst mode without receiving an individual "enable transmission" command, the SKYLink NMS can only adjust AES operations after potentially offending transmissions have occurred.[32] In response, ARINC confirms that its NMS can only react to the number of AESs attempting to access the network in the preceding 250 milliseconds, and thereafter issue a "throttle" command to the AESs over the forward link.[33] Of course, geosynchronous delay will add another 250 milliseconds until this throttle command is received by the offending AES. This half-second lag-time in eliminating offending transmissions raises a significant potential for harmful interference

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[30] *See Boeing Comments* at 7.

[31] *See* SKYLink Technical Exhibit at 3.

[32] *See Boeing Comments* at 7.

[33] *See* SKYLink Technical Exhibit at 2.

into FSS operations.

Boeing also requested that the Commission require ARINC to address the special circumstances of locating a malfunctioning terminal that is mobile and intermittently transmitting in burst mode.[34] In response, ARINC failed to acknowledge that such a transient interference event is much harder to correlate to a given terminal (or even identify as originating from a given AMSS system), instead merely noting that each packet contains a unique IP address that can be associated with an individual AES.[35] However, an IP address would not be useful to another system trying to identify an interference source because it is unlikely that the interference could be demodulated. Such information is also useless if the transmitted signal is not being correctly received by the NMS, as with a malfunctioning AES attempting to log in. Thus, the SKYLink application remains deficient in this area.

B. Aggregate Off-Axis E.I.R.P. Issues

In its comments, Boeing pointed out that the SKYLink system did not appear to account for antenna mis-pointing in the calculation of off-axis e.i.r.p., and that failure to account for this variable is inconsistent with Recommendation ITU-R M.1643 and the Commission's AMSS licensing precedent.[36] Boeing also questioned ARINC's claim that it would have less than a 0.1° total root mean square ("rms") pointing error for the SKYLink system, and estimated that the actual rms pointing error would be several times greater than the given value based on its evaluation of similar systems.[37] After further analysis, Boeing's estimate for the pointing error

[34] *See Boeing Comments* at 8.

[35] *See ARINC Response* at 9.

[36] *See Boeing Comments* at 8-9 (citing Recommendation ITU-R M.1643 at Annex 1 (Part A, Section 2) and *Boeing Transmit/Receive Order* at ¶ 19(h)(5)).

[37] *See Boeing Comments* at 9-10.

of an antenna pointing system based on aircraft inertial navigation system ("INS") data only and without local rate gyros or radome squint compensation, like the SKYLink system, is 0.59 degrees in azimuth (1 sigma) and 0.38 degrees in elevation (1 sigma) for a cone error of 0.71 degrees (1 sigma).[38] As was required of Boeing, ARINC should be required to perform its own analysis of the pointing errors that account for all relevant factors for the SKYLink proposal and present the results to the Commission.

ARINC's Response confirms that actual AES pointing error is not included in its off-axis e.i.r.p. calculation. Indeed, ARINC declined to provide any information on the actual pointing error of SKYLink AESs.[39] Instead, ARINC simply states, without any support, that the off-axis e.i.r.p. increase caused by mis-pointing of 0.6 degrees is less than the 1 dB margin designed in the SKYLink system.[40]

As an initial matter, Boeing's independent calculations reveal a 1.9 dB increase in off-axis e.i.r.p. for an AES with 0.6 degree pointing error.[41] More important, as noted in Boeing's initial comments, Ku-band AMSS systems *must* specifically account for pointing error in controlling off-axis e.i.r.p. and not attribute it to a catch-all margin. In addition, as indicated

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[38] This estimate is based on the ARINC 704 standard for INS data accuracy and latency for heading (0.4 degrees, 110 msec), pitch (0.1 degrees, 50 msec), and roll accuracy (0.1 deg, 50 msec); and other parameters that Boeing can estimate based on its experience designing and integrating mechanically steered antennas to provide Ku-Band AMSS service.

[39] ARINC claims that a "single AES antenna transmitting with a RSS pointing error of 0.1 degrees would only increase its off-axis power density by approximately 0.175 dB," which "was taken into account when calculating the equivalent antenna power spectral density." *See* SKYLink Technical Exhibit at 4. However, ARINC does not explain how this was taken into account, nor does it link the 0.1 degree/0.175 dB figures to the actual pointing error of SKYLink AESs.

[40] *See id.*

[41] This calculation is based on a 4.8 degree parabolic beamwidth with the minimum off-axis e.i.r.p. margin point occurring at 3.4 degrees from the beam peak.

above, it appears that the SKYLink system may not have a 1 dB margin, as claimed. This is of particular concern since it is also unclear what other control errors and additional uncertainties may be charged against this margin.

ARINC compounds its errors by claiming that given the large number of AESs simultaneously accessing the system and that the pointing errors are uncorrelated, it is unlikely all of the AESs transmitting simultaneously would be mispointed by 0.6 degrees. According to ARINC, a maximum number of 62 AESs can simultaneously access the SKYLink system at 32 kbps, less than the 80 supposedly taken into account in its worst-case link budget.[42] However, the relevant inquiry is the minimum number of simultaneous co-frequency accesses that it takes to reach the off-axis e.i.r.p. limits. If the 62 slots for 32 kbps access are divided between two sub-bands and occupied by 128 kbps users, then as few as eight users will fill each sub-band to capacity[43]. For eight users with an azimuth error of 0.59 degrees, the RMS pointing error along the GSO arc is 0.21 degrees (1-sigma). The 99.99% (3.72 sigma) pointing error, considered by the ITU-R studies and used by Boeing in designing and implementing the Connexion system, is 0.79 degrees. This error is substantial and would produce an increase in off-axis e.i.r.p. of 2.5 dB, far more than SKYLink's claimed 1 dB margin.

Similarly, Boeing noted in its comments that ARINC did not appear to account for AES e.i.r.p. variation in its calculation of off-axis e.i.r.p.[44] In its Response, ARINC explains that it accounts for e.i.r.p. variation by using a "worst case" AES e.i.r.p. from Bangor, Maine in the

[42] *See id.*

[43] As discussed below, if Bangor, Maine is considered to be the worst cased location for e.i.r.p. variation, then the number 32 kbps accesses would be reduced to 28 in one 14.4 MHz sub-band. The corresponding number of 128 kbps accesses would be reduced to seven.

[44] *See Boeing Comments* at 9-10.

calculation of the maximum number of simultaneous AES transmissions.[45] While using the worst case AES e.i.r.p. may be a valid approach, ARINC does not appear to have used Bangor in its calculations and Bangor may not be the actual worst case situation.

Given the substantial inconsistencies in the maximum number of simultaneous AES accesses used in ARINC's off-axis e.i.r.p. calculations, it is not clear that ARINC actually used Bangor in the analysis.[46] The maximum input power for 32 kbps from Bangor, Maine is –38.76 dBW/4 kHz.[47] Assuming this input power, it takes 28 simultaneous accesses to reach the –24.25 dBW/4 kHz aggregate input power limit of the SKYLink system. Thus, the number of simultaneous AES accesses must be limited to 28 in a single sub-band, and not the 38, 40, or 66 claimed by ARINC at various points in its submissions. Likewise, the number of simultaneously logged-in AESs must be reduced from 214 in accordance with the statistical function relating the number of logged-in and the number of simultaneously transmitting AESs.[48]

It is also questionable whether Bangor, Maine is actually the "worst case" location in the coverage area. While Bangor may be the worst case major city in the coverage area, aircraft are not limited to flying over major cities and ARINC itself admits that Bangor is actually in the worst 10% of SKYLink's proposed service area.[49] Thus, there may be many locations (up to

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[45] *See* SKYLink Technical Exhibit at 5.

[46] ARINC references 38 or 40 simultaneous accesses in a 14.4 MHz sub-band on page 2 of the SKYLink Technical Exhibit, but ARINC uses 62 out of 80 possible simultaneous accesses (presumably in two sub-bands, so that 31 out of 40 simultaneous accesses are permissible in one 14.4 MHz sub-band) in its worst case link budget. The SKYLink Application separately describes the maximum number of simultaneous accesses as 28 to 66 simultaneous accesses, with 38 being used for the analysis. *See ARINC Application*, Technical Exhibit at 45.

[47] *See id.* at 25.

[48] *See id.* at 46; *see also ARINC Response* at 6.

[49] *See* SKYLink Technical Exhibit at 5.

10% of the proposed service area), that have substantially worse coverage characteristics than Bangor. Furthermore, Boeing has observed executive aircraft operating in its system to fly off the edge of a satellite coverage map on the way to distant locations and, as the aircraft transits out of the coverage area, the G/T of the satellite drops off rapidly while the closed loop power controller turns up the transmit power of the AES to compensate. This is not an issue for the Connexion system because Boeing books the actual e.i.r.p. reported by the AES in real time, and employs positive control to ensure that the aggregate off-axis e.i.r.p. levels are not exceeded. However, the SKYLink system would continue to book this aircraft as having the transmit e.i.r.p. for Bangor. Of course, such failures to account properly for AES off-axis e.i.r.p. would give rise to the potential for harmful interference into adjacent Ku-band FSS networks. Thus, ARINC should be required to use the actual worst-case AES e.i.r.p. in calculating the maximum number of simultaneous accesses in the SKYLink system.[50]

Boeing also noted that ARINC must account for the accuracy with which it knows the e.i.r.p. of its AESs, and raised questions with respect to ARINC's "reverse calculation" methodology.[51] ARINC has partially addressed this issue by describing a ground transmitter with the waveform of the return link to "calibrate, track, and maintain the accuracy of each AES's e.i.r.p."[52] While this is certainly a more accurate approach than the pure reverse calculation method implied by the SKYLink Application, this technique still has errors that ARINC should identify and evaluate (*e.g.*, those deriving from the e.i.r.p. accuracy of the

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[50] Alternatively, ARINC could alter its system to actually use Bangor as the worst case e.i.r.p. by limiting the transmit power for a given data rate to that permitted for Bangor, or by shutting off AESs on aircraft that fly beyond the G/T contour of Bangor.

[51] *See Boeing Comments* at 10-11.

[52] *See* SKYLink Technical Exhibit at 4.

calibration transmitter and any other inputs into the calculation of absolute AES transmit e.i.r.p.). ARINC should perform a tolerance build up for this method and account for these errors in the off-axis e.i.r.p. calculation by reducing the number of simultaneous AES transmissions in proportion to the error.

Boeing further indicated in its initial comments that the SKYLink system employs a Paired Carrier Multiple Access ("PCMA") scheme whereby the forward and return links operate co-frequency in the same transponder, and the forward uplink off-axis e.i.r.p. must be included in the system aggregate.[53] In response, ARINC references its compliance with Section 25.202(f) of the Commission's rules, which is clearly irrelevant since it addresses only out-of-band emissions.[54] ARINC's other argument that the off-axis e.i.r.p. contribution of the forward link can be neglected because it is small under normal conditions is also incorrect.[55] The SKYLink forward link uses a Section 25.209-compliant antenna that is authorized to an input power of –17.4 dBW/4 kHz,[56] resulting in an off-axis e.i.r.p. of as little as 3.4 dB below the applicable limits without factoring in any AES transmissions. Accounting for this off-axis e.i.r.p. in the SKYLink system's aggregate e.i.r.p. would require that the number of simultaneous return link AES accesses be reduced by approximately 45%. Even under normal operating conditions, the number of accesses would need to be reduced by approximately 12.5%.[57] Of course, ARINC should account for the worst case off-axis e.i.r.p. from the forward uplink in calculating the

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[53] *See Boeing Comments* at 11.

[54] *See ARINC Response* at 8.

[55] *See* SKYLink Technical Exhibit at 4.

[56] *See id.*

[57] These number might be mitigated somewhat by using an antenna that exceeded the performance requirements of Section 25.209 of the Commission's rules.

aggregate off-axis e.i.r.p. of the SKYLink system.

Finally, ARINC should provide revised Figures 5-1 and 5-2 showing the 99.99% off-axis e.i.r.p. envelope including *all of the factors* that affect off-axis e.i.r.p. At a minimum this calculation should include pointing error, e.i.r.p. variation and accuracy, and e.i.r.p. from the forward uplink under the peak (worst case) traffic conditions. The principle assumptions of this analysis should be described so they can be evaluated adequately by the Commission and interested parties.

C. Other Issues

In its Response, ARINC claims to be compliant with Recommendation ITU-R M.1643 provisions for the protection of Radio Astronomy stations at altitudes above 30,000 feet with an elevation angle of 30 degrees.[58] This suggests that in order to comply with Recommendation ITU-R M.1643, ARINC should incorporate a mechanism into the SKYLink system that shuts off AESs aboard aircraft with an altitude less than 30,000 feet within line-of-sight of Radio Astronomy stations.

Lastly, if the Commission ultimately grants the SKYLink Application, it should require ARINC to submit a report verifying its ability to comply with all AMSS license conditions imposed by the Commission prior to commencing commercial operations.[59] ARINC suggests that this requirement "makes no sense."[60] The Commission required Boeing to submit actual test data to confirm Boeing's ability to meet the conditions imposed in its AMSS license prior to

[58] In the replacement pages for the SKYLink Application submitted with its Response, ARINC claims an additional 5 dB of frequency isolation and 10 dB of body shielding to achieve compliance. *See ARINC Response* at replacement pages 48-49.

[59] *See Boeing Comments* at 14.

[60] *See* SKYLink Technical Exhibit at 4.

commencing commercial operations.[61] The same requirement should be imposed on all future AMSS systems licensed by the Commission, at least until service and licensing rules are established for AMSS.

V. THE COMMISSION SHOULD DESIGNATE THE ARINC APPLICATION PROCEEDING AS "PERMIT-BUT-DISCLOSE" UNDER THE COMMISSION'S *EX PARTE* RULES

In its initial comments, Boeing urged the Commission to designate this application proceeding as "permit-but-disclose" under its *ex parte* rules because of the significant technical and policy issues raised in the *ARINC Application*, because the Commission's determinations with respect to the application could impact future AMSS licensing proceedings, and because the issues raised in this proceeding overlap many of those matters raised in RM-10800 (the AMSS rulemaking proceeding), which is a "permit-but-disclose" proceeding.[62] ARINC did not oppose this request.

The *ARINC Response* raises significant new questions and heightens Boeing's prior concerns regarding ARINC's Ku-band AMSS proposal, underscoring the need for "permit-but-disclose" status for this application proceeding. Such a status would enable the parties to address the complex technical issues associated with the *ARINC Application* without being burdened by the restrictive ex parte rules for adjudicatory matters. Accordingly, Boeing reiterates its request to designate this AMSS application proceeding as "permit-but-disclose" at the earliest possible time.

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[61] *See Connexion Transmit/Receive Authorization* at ¶19(h)(5).

[62] *See Boeing Comments* at 13.

VI. CONCLUSION

Through domestic licensing proceedings, and the development and adoption of an ITU-R technical recommendation and associated international allocation, the Commission and the international community have established a baseline for Ku-band AMSS services. Boeing has carefully designed and implemented its Connexion system to protect primary Ku-band FSS operations and other co-frequency services in accordance with these requirements. Boeing urges the Commission to ensure that the SKYLink system also operates in accordance with relevant ITU-R and Commission requirements, and will protect other users of the Ku-band to the same high standards imposed on the Connexion system.

Although Boeing welcomes the potential entry of an alternative AMSS service provider in the Ku-band, significant technical questions remain unanswered regarding the SKYLink system and certain aspects of ARINC's proposal are inconsistent with the Commission's AMSS licensing precedent and Recommendation ITU-R M.1643. Until these outstanding issues are resolved, either through demonstrated compliance with applicable requirements or modification of such requirements in the upcoming AMSS rulemaking proceeding, the Commission should not authorize the operation of the SKYLink system.

Respectfully submitted,

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December 18, 2003

CERTIFICATION OF PERSON RESPONSIBLE FOR PREPARING ENGINEERING INFORMATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this pleading, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this pleading, and that it is complete and accurate to the best of my knowledge and belief.

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CERTIFICATE OF SERVICE

I, Todd B. Lantor, hereby certify that a true and correct copy of the foregoing Further Comments of the Boeing Company filed on behalf of The Boeing Company was sent via U.S. mail, postage prepaid, this 18th day of December 2003, to the following:

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INTERNATIONAL TELECOMMUNICATION UNION

RADIOCOMMUNICATION STUDY GROUPS

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United States of America

WORKING DOCUMENT ON PROTECTION OF GSO FSS NETWORKS FROM HARMFUL INTERFERENCE DUE TO A AERONAUTICAL MOBILE SATELLITE SERVICE (AMSS) SYSTEM IN THE BAND 14-14.5 GHz

1 Introduction

Resolution 216 of the WRC-2000 invites the ITU-R to carry out technical and operational studies on the feasibility of sharing the band 14-14.5 GHz with other services in the band, in time for WRC-03. The Chairmen/Vice-Chairmen meeting following WRC-2000 assigned lead responsibility for this agenda item to WP 8D. Other working parties are expected to provide analytical support in their areas of interest.

This contribution intends to demonstrate the feasibility of operating an AMSS service in the 14-14.5 GHz band, as a secondary service, without causing harmful interference to the primary service geostationary orbit ("GSO") fixed satellite service ("FSS") systems[1] .This paper describes a methodology for how an AMSS system can operate and not cause harmful interference to GSO FSS systems. A subsequent contribution will apply this methodology to an AMSS system.

2 Description of the AMSS service

A growing demand exists for two-way broadband communication services that are globally available for use by industry and consumers. A relevant portion of this demand involves the non-safety of life data and communication needs of the aviation industry, including airline passengers and aircraft cabin crews. At least one new service is being developed and tested to provide broadband communications for this largely unserved airborne community using existing and new GSO FSS satellites in the 14.0 to 14.5 GHz band for aicarft-to-space links and in portions of the 11.7 to 12.7 GHz band (depending on which Region is involved) for space-to-aircraft links.

The system is designed to operate in the FSS 12/14 GHz bands for a number of reasons, most notably the dimensional limitations of an aircraft-mounted antenna; propagation impairment due to rain at the higher frequencies; and the current worldwide availability of GSO FSS satellite networks

[1] Operational parameters for the proposed secondary service for AMSS to protect other primary and secondary services, including fixed and mobile services, space research, radionavigation, and radio astronomy, will be the subjects of separate papers in other ITU-R groups.

in the band. With respect to the space-to-aircraft links, the system is designed to operate within the usual constraints of FSS transmissions in the band and thus no new technical studies are needed to address the airborne use of the band. With respect to the aircraft-to-space return links, the transmission from an airborne platform to a GSO FSS satellite in the 14.0-14.5 GHz band needs to be examined to ensure that AMSS can operate in the band on a secondary[2] basis i.e, without causing harmful interference to other services with allocations in the band.

3 Interference requirements to demonstrate the feasibility of AMSS operation in a GSO FSS environment

LMSS and MMSS systems in the 14-14.5 GHz band have been licensed on a case by case basis by a number of nations and have been operating on a secondary basis for many years without any reports of harmful interference to GSO FSS networks. These mobile satellite systems operate under a number of conditions that control the interference they cause to GSO FSS networks. Using this experience as a precedent, it can be expected that further study will show an AMSS system operating under a set of conditions for the aeronautical environment in the 14-14.5 GHz band will not cause harmful interference to GSO FSS networks.

The characteristic of a system that has the potential to cause interference to GSO FSS satellites is its aggregate EIRP density along the GSO arc. From the perspective of a GSO FSS space station the important criterion is the amount of unwanted energy that is being directed towards it. The GSO FSS satellite can not distinguish the altitude, velocity, or other characteristics of the transmitter that is generating the unwanted energy. The use of an aggregate parameter properly accounts for spread spectrum multiple access systems which may have more than one terminal operating simultaneously at the same frequency. An aggregate may need to include any other systems sharing the transponder co-frequency. The use of a spectral density parameter as an operational control accounts for the difference in signal power, bandwidth, and modulation. The calculation of an aggregate EIRP density also must account for the uncertainties in transmitter antenna pointing, aging, environmental conditions, and power control.

Specific regulatory limits do not exist for Earth-to-space transmissions of LMSS and MMSS systems in the 14-14.5 GHz band because they are secondary services. Authorizations for MSS operation in the Ku-band are on a secondary basis and shall not cause harmful interference to the primary service. If there is harmful interference, the secondary service must correct its operation.

However, there are situations where administrations have accepted, on a domestic or regional basis, operating limits for these type of services. For example, the European Telecommunications Standard Institute ("ETSI") has issued a standard for transmissions land mobile earth stations in the 14-14.5 GHz band (ETS 300 255). This standard specifies that the emissions from a *single* land mobile Earth station along the GSO arc shall not exceed:

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2 As indicated in ITU-R Radio Regulation S.5.28, stations of a secondary service: (a) shall not cause harmful interference to stations of primary services to which frequencies are already assigned or to which frequencies may be assigned at a later date; (b) cannot claim protection from harmful interference from stations of a primary service to which frequencies are already assigned or may be assigned at a later date; and (c) can claim protection, however, from harmful interference from stations of the same or other secondary service(s) to which frequencies may be assigned at a later date.

Angle off-axis		Maximum EIRP in any 40 kHz band
2.5°	$\leq \varphi + \delta\varphi \leq 7°$	$33 - 25 \log (\varphi + \delta\varphi) - 10 \log K$ dBW
7°	$< \varphi + \delta\varphi \leq 9.2°$	$12 - 10 \log K$ dBW
9.2°	$< \varphi + \delta\varphi \leq 48°$	$36 - 25 \log (\varphi + \delta\varphi) - 10 \log K$ dBW
48°	$< \varphi + \delta\varphi \leq 180°$	$-6 - 10 \log K$ dBW

Where $\delta\varphi$ is a pointing error term equal to the greater of the RMS antenna tracking error or twice the static RMS antenna pointing error. K is the power density ratio between a fully loaded system and a single land mobile earth station. The $\delta\varphi$ and 10 logK terms relate the emissions of a single terminal to the aggregate level for the system. Removing these terms gives the aggregate level for the system.

It is noted here that the ETSI standard is for a 3° satellite spacing environment in Europe only and not applicable worldwide. Further study is needed to determine appropriate levels for the worldwide service proposed in this document.

A key element of the existing LMSS and MMSS systems that allows them to control their aggregate emissions is network control. Network control ensures that the sum of all of the terminals transmitting simultaneously at the same frequency and pointing to the same satellite does not exceed the desired EIRP density level by managing the entry of new terminals in to the network and the power settings of terminals so that the operation will not cause harmful interference to the primary service. Existing LMSS and MMSS system use a transmit-on-command system. This assures that the antenna is properly pointed when transmitting, since it will not receive a command if the system is not pointing towards the correct satellite. Since these systems use equal EIRP terminals, the aggregate EIRP density is controlled by limiting the total number of users on a transponder. Any feasible AMSS system will have to include network control appropriate for transmitters in an airborne environment.

4 Summary

This contribution concerns an AMSS system that is planned to operate in the 14-14.5 GHz band on a secondary basis. Thus, it should have transmission characteristics that fully protect the GSO FSS systems in the band from harmful interference. A subsequent contribution will demonstrate how a proposed AMSS system can produce an aggregate EIRP density that will not cause harmful interference to GSO FSS systems in the 14-14.5 GHz band; also to be addressed is protection of NGSO FSS systems.

INTERNATIONAL TELECOMMUNICATION UNION

RADIOCOMMUNICATION STUDY GROUPS

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WORKING DOCUMENT TOWARDS DRAFT CPM TEXT IN RESPONSE TO RESOLUTION 216 (WRC-2000): SYSTEM CHARACTERISTICS AND GSO FSS SHARING STUDY FOR A PROPOSED AMSS SYSTEM IN THE 14.0-14.5 GHz BAND

1 Introduction

Agenda item 1.11 for WRC-03 is:

> To consider possible extension of the allocation to the mobile-satellite service (Earth-to-space) on a secondary basis in the band 14-14.5 GHz to permit operation of the aeronautical mobile-satellite service as stipulated in Resolution 216 (Rev.WRC-2000);

Resolution 216 (Rev.WRC-2000) in turn invites ITU-R:

> to complete, in time for WRC-03, the technical and operational studies on the feasibility of sharing of the band 14-14.5 GHz between the services referred to in considering c) [above] and the aeronautical mobile-satellite service, with the latter service on a secondary basis.[1]

Although the CPM-03 meeting following WRC-2000 assigned WP 8D the primary responsibility for the preparation of draft CPM text related to Agenda item 1.11 and Res. 216, several other ITU-R working parties and study groups (including WP 4A) were requested to contribute studies in the area of their expertise. The band 14.0-14.5 GHz is allocated on a primary basis to Fixed Satellite Service (FSS) and is used heavily for geostationary (GSO) FSS worldwide. The sharing analysis presented in this paper deals with the proposed AMSS Earth-to-space link operating on a secondary basis and the GSO FSS Earth-to-space link.

2 Aeronautical mobile satellite service system overview

Aeronautical mobile satellite service (AMSS) in the 14.0-14.5 GHz band is being proposed to meet a growing demand for two way broadband communication by passengers and operators of commercial and business aircraft. At least one system of this type is being developed.

The proposed system uses the "dependent" approach identified in Temp 26E from the October 2000 meeting of WP 4A. That is, the proposed AMSS system will operate within the envelope of FSS technical requirements and coordination agreements reached for particular FSS satellites in lieu of the coordinated FSS assignments.

[1] The services listed in considering c) of Resolution 216, are: fixed-satellite (E-s), radionavigation, fixed and mobile, except aeronautical mobile, services.

The system will operate in the 14.0-14.5 GHz band for aircraft-to-space links and in portions of the 11.2-12.75 GHz band (depending on the Region) for space-to-aircraft links. Each forward link from the ground to the aircraft via satellite, uses a FSS transponder that is received by many airborne terminals. Each airborne terminal may receive multiple forward links from the same satellite. For the return link from the aircraft to the ground via satellite, a FSS transponder is shared among multiple airborne terminals. Separate FSS transponders are used for forward and return links.

The AMSS system will have rigorous, centrally controlled protocols for airborne terminal entry into the network; authorization for the terminal to transmit; controlled authorization to change transmit power/data rates and transponder assignment; and the ability to terminate airborne terminal transmissions; and is proposed to operate on a secondary basis. As part of this control, the transmit power from each airborne terminal is monitored on the ground by the network operation centre (NOC) and managed within a narrow range on an individual and aggregate (per transponder) basis. The NOC also keeps track of the location and heading of each authorized aircraft in flight. Finally, extensive fault management both on the ground and in the airborne terminals assures that no transmission will occur from any airborne terminal without positive control from the ground. In order to monitor the function of mobile terminals, the system will include a method to identify airborne terminals and verify their off-axis performance. The NOC is the central subsystem of the AMSS system in controlling interference to the spaceborne and terrestrial systems operating within the 14-14.5 GHz band.

The airborne terminal will automatically cease transmission should contact with the NOC be lost or should the NOC fail to send the periodic "keep alive" confirmation of authorization to transmit.

Detailed AMSS system parameters are provided in the Attachment 1. Transmit antenna patterns are provided in Attachment 2.

3 Interference evaluation model

In the proposed system, the NOC must accurately model the aggregate emissions of AMSS terminals in order to accurately control those emissions. The ability of the NOC to accurately model the aggregate off-axis e.i.r.p. density of the AMSS terminals sharing a transponder is determined by a variety of factors such as antenna pointing error, power control error, and others. The purpose of this analysis is to show that the NOC can accurately model and control the aggregate emissions of AMSS terminals with a high level of confidence.

The analysis includes errors in:

- Aircraft antenna pointing.
- Aircraft antenna gain pattern.
- Power control.
- Position reporting and reporting latency.
- Aircraft e.i.r.p. estimation.

For this analysis a Monte Carlo simulation of the proposed system has been constructed. In this simulation, scenarios are created by adding randomly generated aircraft to the network until the algorithm employed by the NOC determines that adding an additional aircraft will cause the aggregate emissions to exceed a given design limit. For each scenario, a number of random trials are generated by computing "actual" aggregates using randomly generated errors. Each trial represents a test of the NOC's ability to model and control the aggregate emissions to a given design limit. The simulation generates 4 000 or more scenarios and 25 trials for each scenario for a total of more than 100 000 trials. The results of the trials are then evaluated to determine whether the design limit was met with the desired level of confidence.

The design limit for the aggregate off-axis e.i.r.p. density used in this analysis is:

Angle off-axis	*Maximum e.i.r.p. in any 4 kHz band*
$1° \leq \varphi \leq 7°$	$15 - 25 \log \varphi$ dBW
$7° < \varphi \leq 9.2°$	–6 dBW
$9.2° < \varphi \leq 48°$	$18 - 25 \log \varphi$ dBW
$48° < \varphi \leq 180°$	–24 dBW

with a 99.99% confidence. A 1 dB unallocated system margin is subtracted from this. This margin is intended to account for unknown effects and failures in the system.

The design limit is used only for evaluation purposes and was selected as a test of the system because of its relative stringency. This limit is being used by a Region 2 administration for blanket licensing earth stations in the FSS[2]. This limit is 14 dB below the limit given in ITU-R Recommendation S.524 and 17 dB below the limit given in Radio Regulation S22.26. Furthermore, the same administration also imposes a 14 GHz uplink antenna off-axis cross-polarization envelope power density limits of:

Angle off-axis	*Maximum e.i.r.p. in any 4 kHz band*
$1.8° < \varphi \leq 7°$	$5 - 25 \log \varphi$ dBW
$7° < \varphi \leq 9.2°$	–16 dBW

Details of the error budget, the generation simulation scenarios, and the algorithm used by the NOC are provided in Attachment 3.

4 Study results

The study results show that the proposed AMSS system can maintain its off-axis e.i.r.p. density to within the design limit with a high level of confidence. Monte Carlo simulations were run for two cases. In the first case, aircraft transmitting at 64 kbps were added to the network until the design limit was reached as determined by the NOC algorithm. This is a typical case where many low data rate aircraft share a transponder. In the second case, a single aircraft was added to the network at the maximum data rate permissible (≤1 024 kbps) by the NOC algorithm. This is an extreme case for the system. In both simulations, the aggregate e.i.r.p. density was below the design limit at least 99.99% of the time.

Details of the study results are provided in Attachment 4.

5 Conclusions

This paper describes a proposed AMSS system and the technical methodology that allows it to share spectrum with GSO FSS systems on a secondary basis. The system described here uses the "dependent" approach identified in Temp 26E from the October 2000 meeting of WP 4A. The proposed AMSS uses network control to ensure that its aggregate emissions operate within the envelope of FSS technical requirements and coordination agreements reached for particular FSS satellites in lieu of the coordinated FSS assignments. The simulations described in this paper demonstrate that the proposed system can control its aggregate emissions to within this envelope with a high level of confidence.

The regulatory treatment of an AMSS system has not been addressed in this document.

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[2] This is equivalent to the limit given by ITU-R Recommendation S.728-1 *Maximum Permissible Level Of Off-Axis e.i.r.p.. Density From Very Small Aperture Terminals (VSATs), recommends* 1 and NOTE 1.

ATTACHMENT 1

AMSS system parameters

This attachment describes a proposed AMSS system using the 14.0-14.5 GHz band.

A System overview

The proposed system is designed to provide in-flight data (internet) and entertainment content to passengers and operators of commercial and business aircraft.

The proposed system is composed of four segments: a space segment which consists of leased transponders on FSS satellites, an airborne terminal segment which consists of AMSS terminals installed on multiple aircraft, a ground earth station segment which consists of one or more FSS Earth stations, and a Network Operations Centre (NOC) segment which controls the aggregate emissions of the AMSS system in order to prevent interference to other co-frequency systems. The ground earth station segment is connected to the NOC segment with redundant high speed data connections. Multiple ground earth stations and NOCs may be included in the system on standby for redundancy.

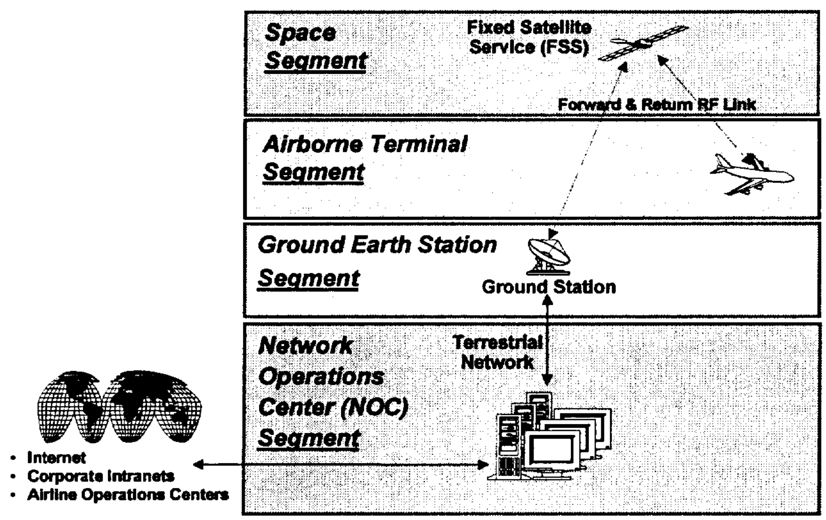

FIGURE A1-1

AMSS system segments

The communication link to the aircraft consists of two parts: one or more forward links and a return link. Each forward link carries data from the ground earth station via satellite to the airborne terminal at a nominal data rate of approximately 5 Mbps. Multiple airborne terminals share a forward link transponder signal, and each airborne terminal may receive signals from multiple forward links on the same satellite. The return link carries data from the airborne terminal via satellite to the ground earth station and uses transponders that are separate from the forward link. Each airborne terminal may transmit at a data rate between 16 kbps and 1 024 kbps. Return link transponders will be shared by multiple airborne terminals using spread spectrum multiple access.

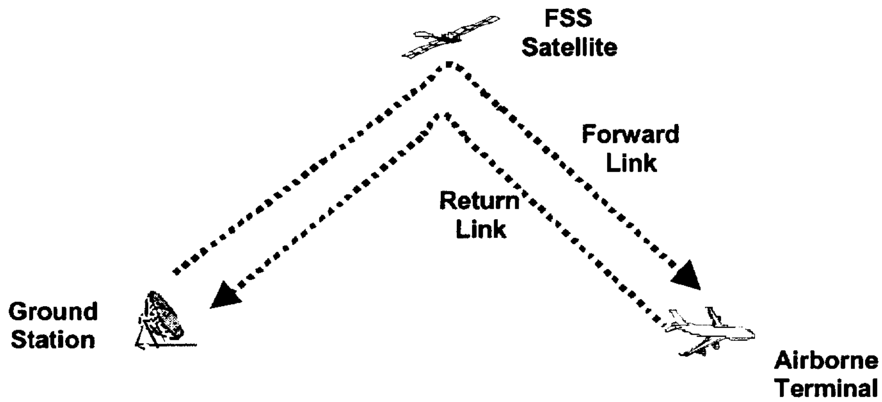

FIGURE A1-2

Airborne terminal links

B System operation

Transmissions from the aircraft are under positive control of the NOC. This control includes airborne terminal entry into the network, authorization of transmission frequencies, authorizations to change the transmit power/data rate, and control of the authorized transmit power level.

For a typical aircraft, the airborne terminal will be powered on when the aircraft cabin power busses receive power. Once data from the aircraft navigation system is available, the receive antenna automatically points to the desired satellite and begins receiving the forward link. The airborne terminal cannot start transmitting to the satellite until it receives authorization from the NOC via the forward link and will automatically cease transmission should contact with the NOC be lost or should the NOC fail to send the periodic "keep alive" confirmation of authorization to transmit.

The NOC periodically polls all inactive airborne terminals using the forward link. The polling message specifies a return link transponder for which the NOC has reserved sufficient capacity, in terms of GSO arc e.i.r.p. spectral density, to allow airborne terminal transmissions. When an airborne terminal that wishes to enter the system receives a polling message, it transmits a response to the NOC over the assigned return link transponder, and the NOC then assigns the airborne terminal "active" status.

Airborne terminals enter the system at the lowest possible transmit data rate, 16 kbps. An airborne terminal may request assignment of higher data rate and transmit power in response to increased return link traffic. When the NOC receives this request, it will first look for spare capacity on the currently assigned transponder; i.e. the new request will still keep the transponder within its set off-axis e.i.r.p. spectral density limit. The airborne terminal will wait for the new assignment before it changes the data rate/transmit power. When the airborne terminal detects reduced passenger demand, it will reduce the data rate/transmit power and notify the NOC of the released capacity.

Return link transponder frequency and polarization, and power/data rate may be reallocated by the NOC at any time while the airborne terminal is active to meet interference limits and traffic demands.

C Power control

Two power control loops are employed in the control of transmissions from individual aircraft. The power control loops will maintain the receive signal Eb/No from each airborne terminal above a threshold Eb/No level corresponding to a 1E-9 bit error rate, and will maintain the time variations of Eb/No within a ± 0.5 dB control range.

In the first loop, the earth station measures the received Eb/No for each airborne terminal and then transmits power level change commands to the airborne terminal to maintain the Eb/No within a narrow control range. This loop has low bandwidth, and manages effects such as variations in path loss as the aircraft moves, and changes in airborne terminal e.i.r.p. due to due temperature variations.

A second control loop within the airborne terminal maintains constant e.i.r.p. during rapid movements of the airborne terminal. Aircraft movements cause changes in the antenna pointing angles resulting in antenna gain changes. These gain changes are calculated from the pointing angles, and the transmit power is rapidly adjusted to maintain constant e.i.r.p.

D Network control of aggregate emissions

Network control of aggregate emissions is the key feature of the system design that allows it to protect co-frequency FSS systems. The NOC is responsible for managing the aggregate emissions of the airborne terminals sharing a FSS transponder so as to fall within the envelope of FSS technical requirements and coordination agreements reached for particular FSS satellites with a high level of confidence. Both the off-axis e.i.r.p. limit and level of confidence to which the NOC manages aggregate emissions are software adjustable from transponder to transponder to meet the licensing requirements of individual administrations and applicable transponder coordination agreements.

The management of aggregate emissions is accomplished as follows:

- Airborne terminals operating within the system automatically report when their position, heading, or attitude change by an amount sufficient to change their off-axis e.i.r.p. pattern by more than 0.1 dB at an adjacent satellite.
- Based on the aircraft location and data rate, its received Eb/No at the ground, and the measured properties of the specific transponder, the NOC computes the e.i.r.p. radiated towards the serving satellite by that aircraft.
- The NOC then calculates the off-axis e.i.r.p. spectral density using a model of the transmit antenna pattern.
- The off axis e.i.r.p. spectral density patterns of all of the aircraft sharing a transponder are aggregated and the aggregate e.i.r.p. spectral density envelope is calculated to a 99.99% confidence level using the known error characteristics of the system. Potential error sources considered in this calculation include:
  - Aircraft Antenna Pointing.
  - Aircraft Antenna Gain Pattern.
  - Power Control.
  - Position Reporting and Reporting Latency.
  - Aircraft e.i.r.p. Estimation.
- A 1 dB unallocated system margin is added.

- By controlling entry into the system and changes in aircraft data rate, the NOC maintains the aggregate emissions within the design limit. If necessary, the NOC can command airborne terminals to a lower data rate or off of the system to ensure compliance.

E Fault management

Positive control of airborne terminals is essential to maintaining control of aggregate emissions. Features are included in the system design to ensure that no transmissions take place from an aircraft unless it is under positive control.

Airborne terminal fault management

- Transmission is inhibited if built-in-test equipment detects any fault in the transmit antenna or on-board transmit control system.
- Transmission is inhibited if communication is lost between the airborne terminal transceiver and the antenna subsystem.
- Transmission is inhibited if the performance of the antenna pointing algorithm exceeds specifications.
- Transmission is inhibited if the airborne terminal loses the receive link.
- Transmission is inhibited until a return link has been assigned from the NOC.
- Transmission is inhibited if the airborne terminal fails to receive a keep-alive signal from the NOC.

Ground fault management

- The ground earth station monitors all assigned return links. If a return link is lost, the corresponding airborne terminal is commanded to stop transmitting.
- If the NOC loses communications with the ground earth station, all airborne terminal connections will timeout and stop transmitting.
- If the airborne terminal fails to properly respond to power control commands, the airborne terminal is commanded to stop transmitting.
- If the airborne terminal fails to properly respond to data rate change commands, the airborne terminal is commanded to stop transmitting.

In order to monitor the function of mobile terminals, the system will include a method to identify airborne terminals and verify their off-axis performance.

F Airborne antennas

The airborne terminal uses separate transmit and receive active phased arrays[3]. The antennas will be mounted on top of the aircraft fuselage and separated from each other by approximately 1.25 metres to prevent self interference. The characteristics of the transmit and receive antennas are shown in Figure A1-3 and A1-4. Prototype transmit antennas are currently being fabricated and receive antennas have been flight tested for a number of years.

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[3] While active phased array antennas are a novel feature of this AMSS system, they are not essential to the development of this service. Phased arrays offer a aerodynamic drag advantage, but other types of antennas are also suitable for AMSS service.

- Active Aperture: 38 cm diameter (uniform illumination)
- Number of Elements: 873
- Maximum e.i.r.p.: 51.2 dBW for at zenith scan, decreasing as a cos (θ°)function of scan angle θ°
- Frequency: 14.0 GHz to 14.5 GHz
- Antenna Beamwidth: 3.2° × 3.5° at zenith, increasing as 1/cos (θ°) in the scan plane as a function of scan angle θ°
- Maximum Scan Angle from Zenith: At Least 63°
- Polarization: Linear

FIGURE A1-3

Summary transmit antenna characteristics

- Active Aperture: 43 × 61 cm (uniform illumination)
- Number of Elements: 1 515
- G/T – 12.5 dB/K at zenith scan, decreasing as a cos (θ°) function of scan angle θ°
- Frequency: At Least 11.7 GHz to 12.7 GHz
- Instantaneous Bandwidth: 500 MHz
- Antenna Beamwidth: 2.1° × 3.1° at zenith, increasing as 1/cos (θ°) in the scan plane as a function of scan angle θ°
- Maximum Scan Angle from Zenith: At Least 63°
- Polarization: Circular, converted to linear after the antenna

FIGURE A1-4

Summary receive antenna characteristics

Both antennas can be electronically scanned to at least their design specification of 63°. In practice the receive antenna has shown acceptable performance at scan angles of up to 70°.

Typical beam patterns for the transmit antenna are contained in Attachment 2.

G Antenna pointing

Accurate pointing of transmit antennas is achieved by closed loop pointing of the receive antenna towards a desired satellite and slaving of the transmit beam to the receive beam direction. Initial acquisition of the satellite by the receive beam is accomplished through the use of the aircraft navigation data.

During normal operation the receive antenna dwells at five points (sequential lobing) about the estimated vector between the aircraft and the satellite and, using the measured receive signal strengths for each of these five points, the true satellite vector is calculated. The receive antenna performs this operation 50 times per second and can accurately point to the satellite during extreme aircraft movements. Simulations of an aircraft manoeuvre close to its maximum operational envelope yielded a root mean square (rms) pointing error of 0.08°. This included aircraft motion between update cycles.

The transmit antenna is continuously pointed in the direction of the satellite as determined by the receive antenna.

The pointing accuracy of the transmit antenna is also affected by installation alignment tolerances, aircraft flexing, antenna squint effects and antenna module differences. Combined with the installation alignment error, the total rms beampointing error for the transmit antenna is calculated to be 0.15° rms.

H Waveform

Both the forward and return link waveforms use direct sequence spread spectrum modulation. This reduces the e.i.r.p. spectral density of the waveform and to allows multiple aircraft to share a return link transponder using spread spectrum multiple access.

The waveform characteristics are listed in Figure A1-5. The aircraft forward link operates at a nominal information rate of 4.86 Mbps and the aircraft return link operates at information rates between 16 and 1 024 kbps. The chipping rate is held constant (independent of data rate) so that the spreading bandwidth is equal to 90% of the transponder bandwidth. For a 27 MHz transponder the spreading bandwidth is 24.3 MHz.

Data Modulation	**Direct Sequence Spread Spectrum**
Chipping Modulation	**Offset-Quadrature Phase Shift Keying ("O-QPSK")**
Spreading Bandwidth	**Approximately 0.9 of Transponder Bandwidth**
Filtering	**Square Root Raised Cosine ("SRRC"), Alpha=0.35**

FIGURE A1-5

Summary of waveform characteristics

I Link budgets

Summary forward and return link budgets are shown below for an airborne terminal with the properties shown in Figure A1-6 and a satellite with the properties shown in Figure A1-7. The position of the aircraft (Seattle, WA) is near the maximum scan angle for the antenna and represent a stressing case for link closure. The link budgets are evaluated for a rain availability of 99.9% at a height of 3.05 km which is the generally first altitude that passengers are allowed to use electronic devices.

- Longitude: 123.6° West Longitude
- Latitude: 47.6°
- Altitude: 3.05 km
- Heading: -20° From North
- Pitch: 0°
- Roll: 0°

FIGURE A1-6

Aircraft position

- Longitude: 93° West Longitude
- Saturated e.i.r.p.: 48 dBW EOC
- G/T: 1 dB/K
- Receive Antenna Gain: 30 dB
- Receive Noise Temperature: 29 dBK

FIGURE A1-7

Serving satellite characteristics

Forward link

The forward link budget is shown in Figure A1-8. The adjacent satellite interference calculation assumes the presence of an interfering cross-polarization transponder on the serving satellite and interfering co-polarization and cross-polarization transponders on the five nearest adjacent satellites on either side with a 2° spacing between orbital locations. Each interfering transponder is assumed to have an e.i.r.p. of 48 dBW that falls entirely within the bandwidth of the AMSS signal. The link budget shows that the aircraft has sufficient margin to close the link at the design availability.

If the system were to operate in a transponder subject to a more severe interference environment, the increased interference noise could be offset by reducing the forward data rate. This allows the system to operate in the most severe interference environment foreseeable. The downlink power spectral density from the satellite would be unchanged because the system operates at a constant chipping rate (bandwidth).

Forward Downlink Budget Summary

Receiver Location		Seattle, WA
Rain Region		D
Transponder Center Frequency	GHz	11.836
Spread Bandwidth	MHz	24.3
Transponder EIRP	dB W	48.0
Clear Sky Path Loss	dB	205.7
Atmospheric Attenuation[1]	dB	0.09
Rain Attenuation[2]	dB	0.50
Polarization Tracking Loss[3]	dB	0.04
Pointing Loss	dB	0.50
Aircraft Receive Antenna Gain	dB	30.8
Receive Power at Aircraft	dB W	-128.0
Information Rate	Mbps dB Hz	4.8 66.8
Eb	dB W/Hz	-194.8
Aircraft Receive Noise Temperature	K dB K	270 24.3
No	dB W/Hz	-204.3
Co-Polarization Interference	dB W	-130.1
Cross-Polarization Interference	dB W	-140.9
Total Receive Interference Power	dB W	-129.8
Io Adjacent Satellite	dB W/Hz	-203.6
No + Io	dB	-200.9
Eb/(No+Io) Downlink	dB	6.1

Forward Link End-to-End Summary

Eb/No Uplink	dB	23.8
Eb/(No+Io) Downlink	dB	6.1
Eb/(No+Io) End-to-End	dB	6.1
Band Limiting Eb/No Degradation	dB	0.3
Eb/(No+Io) Total	dB	5.8
Eb/No Required	dB	4.5
Margin	dB	1.3

FIGURE A1-8

Forward link budget

[1] Atmospheric attenuation is given by ITU-R Recommendation P.676-3, corrected for altitudes above sea level. A sea level water vapor density of 20 g/m3 and a water vapor scale height of 2.1 km based on a rain condition are assumed.

[2] Rain attenuation is given by the greater of the ITU-R Recommendation P.618-6 rain model or 0.5 dB. Rain attenuation is calculated for 99.9% rain availability at the service altitude of 10 000 feet (3 km). Below 10 000 feet, the availability of the service would be diminished. At northern latitudes in North America and Europe, the 0° isotherm may be near or below 10 000 feet resulting in negligible or zero rain attenuation. In order to maintain a minimum level of rain attenuation at northern latitudes, a 0.5 dB rain attenuation "floor" is used.

[3] The airborne terminal linear polarization converter can track the polarization of a signal in increments of 11.25° resulting in a maximum tracking error of 5.63°. The resulting polarization tracking loss is computed based on a 20 dB axial ratio for the satellite and the receive antenna.

Return link

Return link budgets for 16 kbps and 1024 kbps[4] are shown in Figure A1-9. The adjacent satellite uplink interference calculation assumes the presence of interfering uplinks from the five nearest adjacent satellites on either side at a 2° spacing between orbital locations. Each interfering uplink is assumed to have the off-axis e.i.r.p. characteristics given in ITU-R Recommendation 728-1, *recommends* 1 and NOTE 1 as is appropriate for portions of Region 2. The link budget shows that the aircraft has sufficient e.i.r.p. close the link at the design availability.

If the system were to operate in a transponder subject to a more severe interference environment, the increased interference noise could be offset by increasing the transmit power for a given data rate. This would result in a reduced maximum aircraft data rate and a reduced aggregate transponder data rate. For example, if the system were to receive interference from other systems operating at the S22.26 levels over the entire band while maintain its levels to the design limit in section 3, the output back off for a 16 kbps terminal would be reduced from 18.3 dB to 6.6 dB. The aggregate transponder data rate and maximum aircraft data rate would be reduced proportionally. Normal coordination practices make such a severe scenario very unlikely.

[4] The NOC may limit aircraft data rates to below 1024 kbps to meet the aggregate off-axis e.i.r.p. limits in some scenarios.

Return Uplink Budget Summary

Receiver Location		Seattle, WA	Seattle, WA
Rain Region		D	D
Transponder Center Frequency	GHz	14.136	14.136
Spread Bandwidth	MHz	24.3	24.3
Available Transmit EIRP[1]	dB W	47.0	47.0
Output Back Off[2]	dB	18.3	0.8
Transmit EIRP	dBW	28.7	46.2
Clear Sky Path Loss	dB	207.2	207.2
Atmospheric Attenuation[3]	dB	0.12	0.12
Rain Attenuation[4]	dB	0.50	0.50
Polarization Tracking Loss[5]	dB	0.04	0.04
Pointing Loss	dB	0.20	0.20
Satellite Receive Antenna Gain	dB	30.0	30.0
Receive Power	dB W	-149.4	-131.9
Information Rate	kpbs	16.0	1024.0
	dB Hz	42.0	60.1
Eb	dB W/Hz	-191.5	-192.0
Satellite Receive Noise Temperature	K	794	794
	dB K	29.0	29.0
No	dB W/Hz	-199.6	-199.6
Io Adjacent Satellite Uplink	dB W/Hz	-202.5	-202.5
Io Spread Spectrum (Cochannel)	dB W/Hz	-205.0	-210.7
No + Io	dB W/Hz	-197.1	-197.6
Eb/(No+Io) Uplink	dB	5.6	5.6
Return Link End-to-End Summary			
Eb/(No + Io) Uplink	dB	5.6	5.6
Eb/No Downlink	dB	26.9	26.4
Eb/(No+Io) End-to-End	dB	5.55	5.55
Power Control Margin	dB	0.75	0.75
Transponder Implementation Margin	dB	0.30	0.30
Eb/(No+Io) Total	dB	4.50	4.50
Eb/No Required	dB	4.50	4.50

FIGURE A1-9

Return link budget

1 The peak e.i.r.p. for a phased array is scan angle dependent.

2 The airborne terminal transmits with the minimum e.i.r.p. needed to achieve the threshold Eb/No.

3 Atmospheric attenuation is given by ITU-R Recommendation P.676-3, corrected for altitudes above sea level. A sea level water vapor density of 20 g/m3 and a water vapor scale height of 2.1 km based on a rain condition are assumed.

4 Rain attenuation is given by the greater of the ITU-R Recommendation P.618-6 rain model or 0.5 dB. Rain attenuation is calculated for 99.9% rain availability at the service altitude of 10 000 feet. Below 10,000 feet, the availability of the service may be diminished. At northern latitudes in the United States, the 0° isotherm may be near or below 10 000 feet resulting in negligible or zero rain attenuation. In order to maintain a minimum level of worst case rain attenuation at northern latitudes, a 0.5 dB rain attenuation "floor" is used.

5 The transmit antenna can track the polarization of a signal with a maximum tracking error of 5.6°. The resulting polarization tracking loss is computed based on a 20 dB axial ratio for the satellite and the transmit antennas.

ATTACHMENT 2

AMSS transmit antenna patterns

The 873-element transmit antenna patterns in the forward region of the antenna field of view are shown in this section. These patterns are used in assessing the interference to adjacent satellites.

Figure A2-7 shows a surface plot of the antenna pattern for antenna scan angles of $\theta_x = 0°$ and $\theta_y = 0°$. Only sidelobes greater than –40 dB are shown. The sidelobe performance is almost circularly symmetric due to the near-circular shape of the transmit antenna.

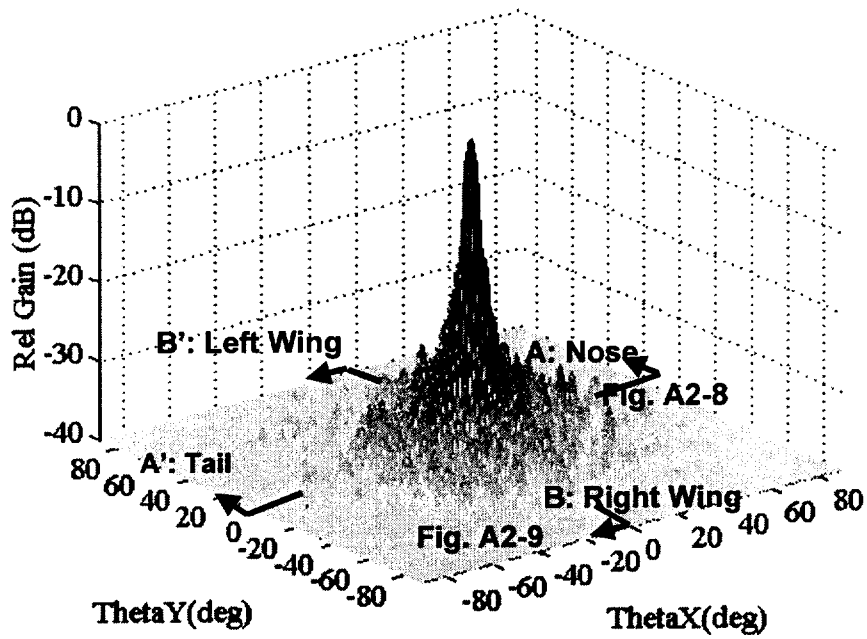

FIGURE A2-7

Surface plot of the transmit antenna pattern for antenna scan angle of θ_x=0° and θ_y=0°

Figures A2-8 and A2-9 are cuts through the principal axes of the antenna pattern for antenna scan angles of $\theta_x = 0°$ and $\theta_y = 0°$. The near-in sidelobe performance is typical of a uniformly illuminated circular aperture. The expanded view of the mainbeam region is shown in each cut.

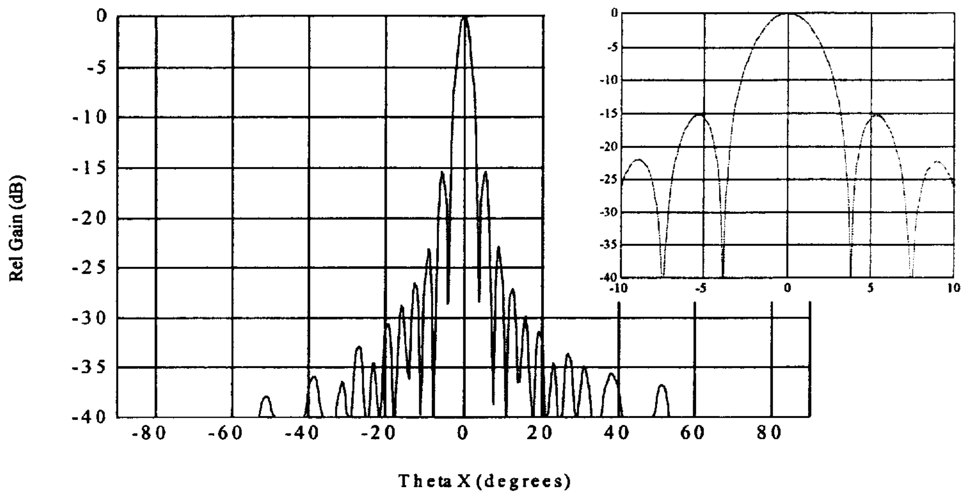

FIGURE A2-8

Transmit antenna pattern cut along θ_x (Cut A-A' in Figure A2-7)

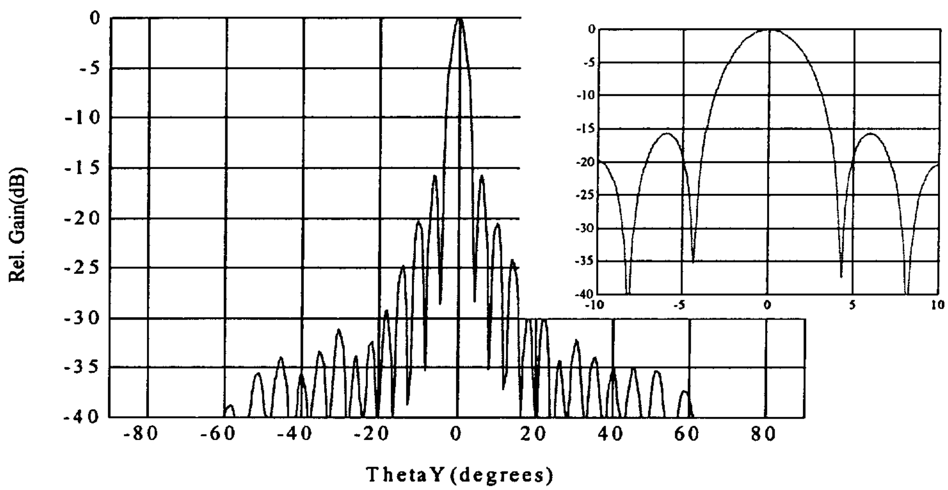

FIGURE A2-9

Transmit antenna pattern cut along θ_y (Cut B-B' in Figure A2-7)

Figure A2-10 shows a surface plot of the antenna pattern for scan angles of $\theta_x = 60°$ and $\theta_y = 0°$. Only sidelobes greater than –40 dB are shown.

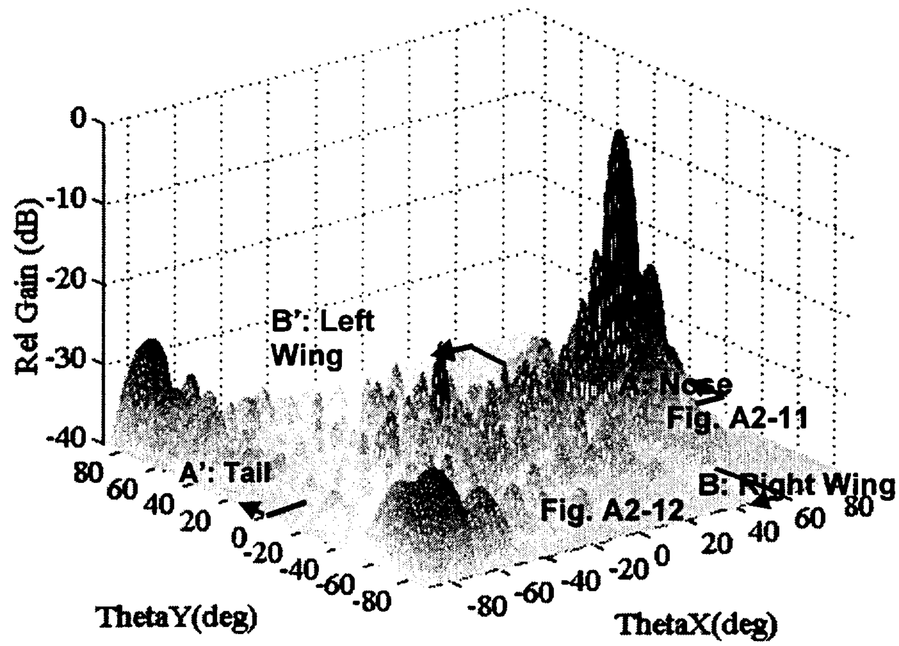

FIGURE A2-10

Surface plot of antenna pattern for antenna scanned to θ_x=60° and θ_y=0°

Figures A2-11 and A2-12 are cuts through the antenna pattern for scan angles of $\theta_x = 60°$ and $\theta_y = 0°$. Figure A2-11 is a cut along the X-axis for $\theta_y = 0°$ of the antenna and Figure A2-12 is a cut along the Y-axis for $\theta_x = 60°$. Figure A2-12 is representative of the maximum sidelobe level that would appear along the GSO arc for an aircraft in the mid latitudes.

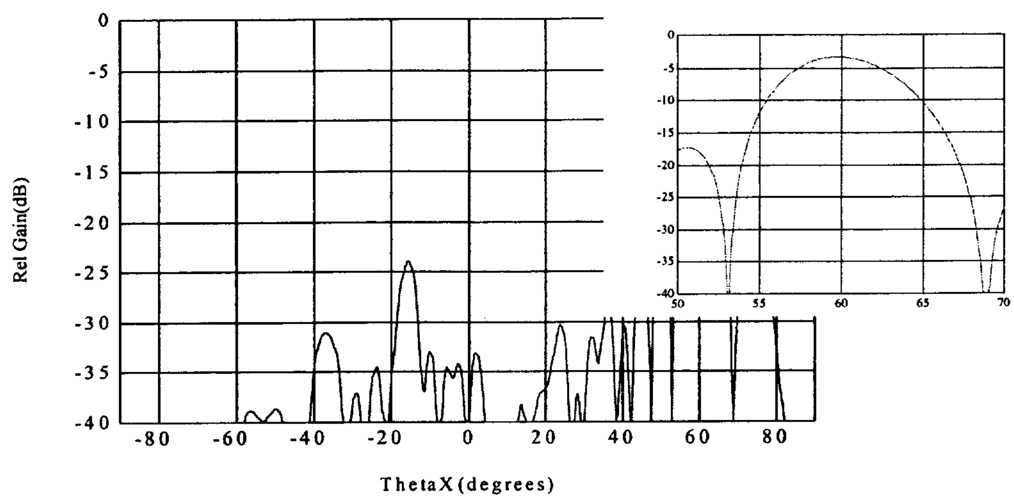

FIGURE A2-11

Transmit antenna pattern cut along θ_x (Cut A-A' in Figure A2-10)

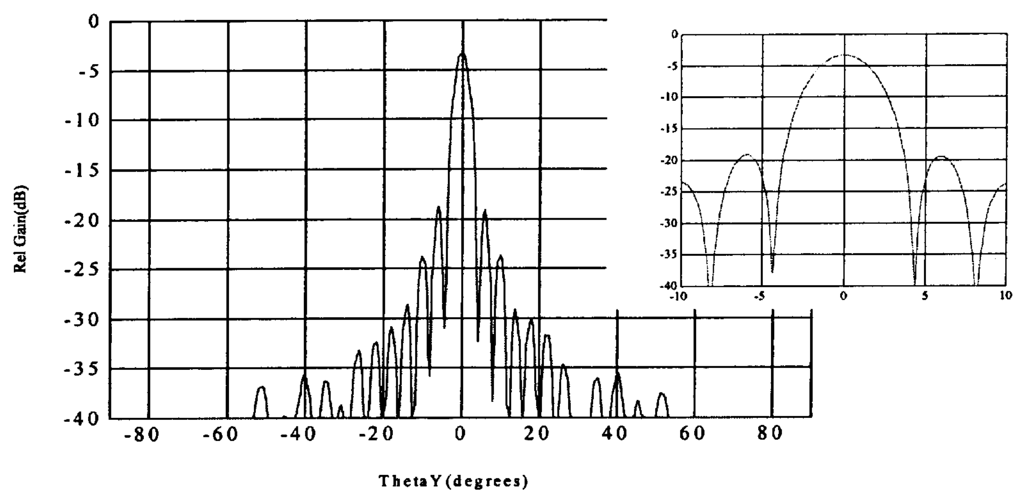

FIGURE A2-12

Transmit antenna pattern cut along θ_y (Cut B-B' in Figure A2-10)

ATTACHMENT 3

Interference evaluation model

This attachment provides details of a Monte Carlo simulation used to evaluate the operation of the proposed AMSS system. Section A describes the error budget used in the simulation. Section B describes how random scenarios are generated. Finally, Section C describes the algorithm used by the NOC to estimate the aggregate e.i.r.p. envelope.

A Random generation of errors

This error budget is based on analysis and simulation of the system. These numbers will be updated as hardware becomes available for testing. The errors considered include:

- Antenna pointing (applied to each aircraft):
  - Tracking: 0.15 deg 1σ.
  - Antenna misalignment: 0.10 deg 3σ.
- Aircraft antenna gain pattern (applied to each antenna element):
  - Amplitude error: 1.5 dB 1σ.
  - Phase error: 5.7 deg 1σ.
  - Quantization error: 4-bit (1:16).
  - Element failure: p = 0.34% Bernoulli distribution (3 elements/antenna in 10 years).
- Power control: 0.5 dB 3σ (applied to each aircraft).
- Position reporting and reporting latency: 0.1 dB 1σ (applied to each aircraft).
- Aircraft e.i.r.p. estimation:
  - Satellite receive antenna gain towards the aircraft: 0.5 dB 3σ (applied to each aircraft).
  - Satellite receive antenna gain towards the calibration transmitter: 0.5 dB 3σ (applied to the aggregate).
  - Calibration transmitter e.i.r.p.: 1.0 dB 3σ (applied to the aggregate).
  - Calibration signal Eb/No measurement: 0.5 dB 3σ (applied to the aggregate).
  - Atmospheric and rain loss: 0.25 dB 1σ (applied to the aggregate).

B Random generation of aircraft scenarios

First, aircraft are randomly generated with the following properties:

- Location: the contiguous US, as shown in Figure A3-1.
- Altitude: 3.05 km to 4.57 km.
- Attitude:
  - Heading: 0 to 360 deg.
  - Pitch: 2 to 5 deg.
  - Roll:
    - 0 deg 95% of the time.
    - ±15 deg 5% of the time.

- Data Rate
  - Case 1: Multiple aircraft at 64 kbps.
  - Case 2: Single aircraft at the maximum allowed data rate (≤1 024 kbps).

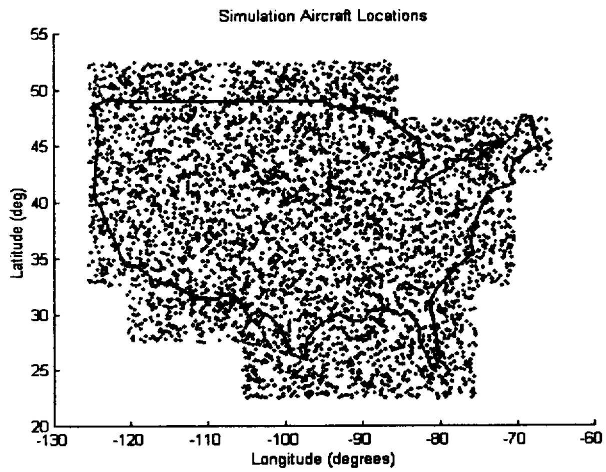

FIGURE A3-1

Aircraft location distribution

Next, scenarios are generated by adding randomly generated aircraft until the algorithm used by the NOC determines that the transponder is full. After each aircraft is generated, the NOC determines whether adding that aircraft will cause the aggregate emissions to exceed a given design limit using an algorithm described in Section C. If the design limit is not exceeded, the process is repeated. If the design limit is exceeded, the aircraft data rate is reduced to the highest data rate in increments of 16 kbps that will meet the limit and no further aircraft are added to the system.

The simulation generates 4 000 or more scenarios. For each scenario, 25 random trials are generated by computing "actual" aggregates using randomly generated errors. Each trial represents a test of the NOC's ability to model and control the aggregate emissions to a given design limit. In total the simulation produces more than 100 000 trials which are used to determine the "actual" 99.99% e.i.r.p. envelope. This envelope can then be compared to the design limit minus a 1 dB unallocated margin to determine the success or failure of the algorithm used by the NOC.

C Algorithm for projection and managing the e.i.r.p. envelope

The algorithm used by the NOC determines when the aggregate off-axis e.i.r.p. density will exceed the design limit by first numerically estimating the mean, μ, and standard deviation, σ, of the aggregate at points along the GSO. This is done by computing 30 samples, where each sample is an aggregate generated using randomly generated errors. Thus, μ and σ are estimated by a mini-Monte Carlo analysis. This approach allows distribution in e.i.r.p. density to be computed from error sources which are not linearly related to e.i.r.p. density, such as pointing error. This approach also captures the sensitivity (or lack of sensitivity) of some scenarios to certain errors.

The NOC then projects the aggregate e.i.r.p. envelope at points along the GSO as $\mu + N\sigma$ where N is a constant selected to give the desired probability level. Finally, the NOC compares the projected e.i.r.p. envelope to the design limits and evaluates whether it can admit additional aircraft to the network and remain below the design limit.

ATTACHMENT 4

Study results

This attachment contains results from the simulation described in Attachment 3.

A Multiple aircraft analysis

The multiple aircraft case represents a the typical usage scenario for the proposed system where a large number of lower data rate, in this case 64 kbps, aircraft share a transponder on a satellite at 93° W Longitude. The aggregate interference is computed at 0.5° intervals between 104° and 82° W Longitude The results of this simulation are given in Figure A4-1. This simulation contains 4118 scenarios and 102,950 trials. For this simulation the NOC has successfully controlled the aggregate off axis e.i.r.p. density to 1 dB below the design limit with a 99.99% level.

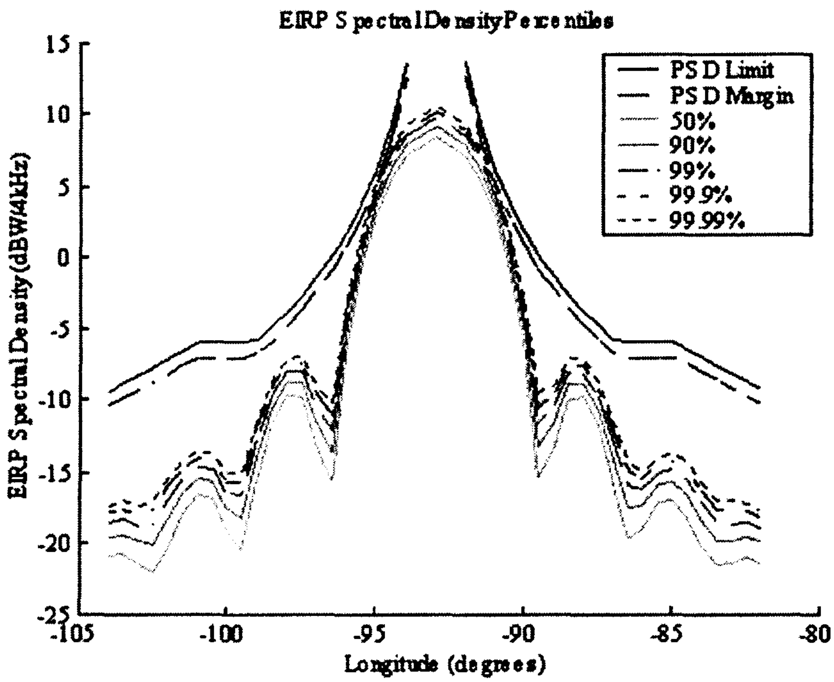

FIGURE A4-1

Multiple aircraft Monte Carlo simulation results

B Single aircraft analysis

The single aircraft case represents an extreme scenario for the proposed system where a single high data rate (≤1 024 kbps) user an entire transponder. The results of this simulation are given in Figure A4-1. This simulation contains 5 000 scenarios and 125 000 trials. For this simulation the NOC has successfully controlled the aggregate off axis e.i.r.p. density to 1 dB below the design limit with a 99.99% level.

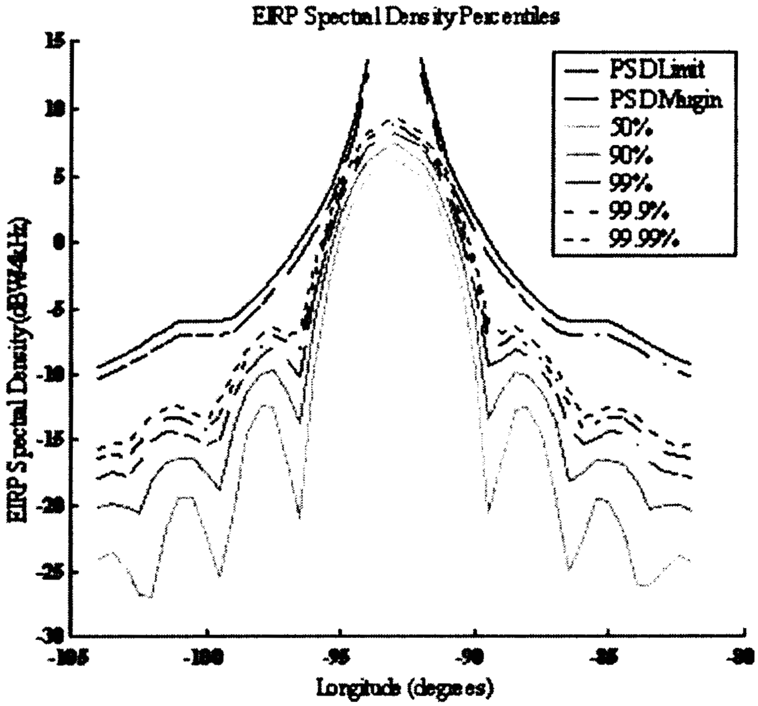

FIGURE A4-1

Single aircraft Monte Carlo simulation results

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