TECHNICAL OPERATIONAL COORDINATION AGREEMENT FOR THE JOINT USAGE OF THE BAND 14.0 - 14.5 GHz BETWEEN THE NATIONAL SCIENCE FOUNDATION AND AIRCRAFT EARTH STATIONS (AES) OPERATING IN THE BOEING℠ CONNEXION AERONAUTICAL MOBILE NETWORK

Version 3.2

March 2, 2004

TECHNICAL OPERATIONAL COORDINATION AGREEMENT FOR THE JOINT USAGE OF THE BAND 14.0 - 14.5 GHz BETWEEN THE NATIONAL SCIENCE FOUNDATION (NSF) AND AIRCRAFT EARTH STATIONS (AES) OPERATING IN THE CONNEXION BY BOEING℠ (CBB) AERONAUTICAL MOBILE-SATELLITE SERVICE NETWORK

Radio Astronomy observations are conducted in the 14.47-14.5 GHz band in the USA at a number of Radio Astronomy sites. The Boeing Company desires to operate a satellite-based, in-flight, broadband communications service, known as the CBB system to commercial, government and general aviation aircraft. The aircraft-to-satellite link of the CBB system plans to operate in the 14.0 - 14.5 GHz band. The present agreement is intended to facilitate operation of the CBB system, without causing interference to Radio Astronomy stations.

1. General Information

1.1 The band 14.47-14.5 GHz is allocated to the radio astronomy service on a secondary basis, for observations of the formaldehyde (H_2CO) line.

1.2 Until the conclusion of WRC-03, the band 14.0 - 14.5 GHz was allocated to the mobile-satellite service except aeronautical mobile-satellite service (Earth-to-space) on a secondary basis.

1.3 The World Radiocommunication Conference 2003 (WRC-03) allocated the band 14.0 – 14.5 GHz to the Aeronautical Mobile-Satellite Service (R) (AMSS(R)) on a secondary basis. **Recommendation ITU-R M.1643, Part C, Annex 1** details protection measures to be implemented by aeronautical mobile-satellite service(R) (AMSS(R)) stations to protect radio astronomy stations that observe in this band.

1.4 The Boeing Company filed an application with the FCC on December 4, 2000 for authority to operate up to eight hundred technically identical transmit/receive mobile earth stations aboard aircraft to operate in the 11.7 – 12.2 and 14.0 – 14.5 GHz frequency bands. These earth stations and the accompanying ground equipment and software constitute the Connexion by Boeing℠ (CBB) system. The FCC released an order, December 21, 2001, granting Boeing's application and issued Boeing a license to operate said transmit/receive mobile earth stations aboard aircraft, subject to, *inter alia,* interference protection of U.S. radio astronomy stations consistent with the present agreement. Boeing has, subsequently, sought and received an amendment to said license on November 11, 2003.

1.5 This agreement document has been developed for AESs operating with the CBB system, and applies to AESs operating on commercial, government and general aviation aircraft.

1.6 The Electromagnetic Spectrum Unit of the National Science Foundation (NSF) has the authority to negotiate and sign this agreement for the radio astronomy sites listed in Section 2.1, and Boeing has the authority to negotiate and sign this agreement for the CBB system..

2. List of NSF supported Radio Astronomy observatories observing or planning to observe in the band 14.47 - 14.5 GHz within the US and its territories

2.1 The following is a list of radio astronomy sites supported by NSF that are included in this agreement. Sites associated with the Very Long Baseline Array (VLBA), which require a different level of protection from the other sites, are noted.

Observatory	Latitude (DMS)	Longitude (DMS)
National Radio Astronomy Observatory (NRAO) sites:		
Green Bank Telescope, WV	38 25 59	79 50 24
Very Large Array, Socorro, NM	34 04 43	107 37 04
VLBA sites:		
St. Croix, VI	17 45 31	64 35 03
Hancock, NH	42 56 01	71 59 12
N. Liberty, IA	41 46 17	91 34 26
Ft. Davis, TX	30 38 06	103 56 39
Los Alamos, NM	35 46 30	106 14 42
Pie Town, NM	34 18 04	108 07 07
Kitt Peak, AZ	31 57 22	111 36 42
Owens Valley, CA	37 13 54	118 16 34
Brewster, WA	48 07 53	119 40 55
Mauna Kea, HI	19 48 16	155 27 29

Additional radio astronomy sites:

Additional radio astronomy sites may be added to this list. In particular, this may include the National Astronomy and Ionosphere Center (NAIC) site at Arecibo, PR (18 20 46 N, 66 45 11 W). NSF shall give Boeing no less than 2 months advance notice of changes in the status of existing sites, or of any additional radio astronomy site being brought into use in the 14.47 - 14.5 GHz band.

3. Technical Operational Coordination Agreement

NSF and Boeing agree to the following:

3.1 The purpose of this agreement is to provide protection to the radio astronomy sites listed in Section 2.1 during periods of radio astronomy observations in the 14.47 - 14.5 GHz band to the following aggregate pfd levels within that band:

a) -221 dB($W/m^2/Hz$) for the Arecibo (if added to Section 2.1), Green Bank and Socorro sites
b) -189 dB($W/m^2/Hz$) for the ten VLBA sites

3.2 This agreement should be reviewed typically on an annual basis by all parties signing this document beginning within one year after Boeing has informed NSF of the start of service in the US under an operational license. The purpose of this review is to assess the effectiveness of this agreement as well as to update as applicable this or successor operational coordination agreements.

3.3 Each party shall inform the other party in a timely manner of changes in the points of contact as defined in Section 5.

Boeing agrees to:

3.4 Cease AES transmissions in the 14.47 - 14.5 GHz band, within line-of sight of radio astronomy stations listed in Section 2.1, during periods of notified radio astronomy observations at the site.

3.5 Control the AES transmitters so that the pfd levels in the 14.47 – 14.5 GHz band produced at radio astronomy sites by individual AESs, during notified periods of observation (see Section 3.7), does not exceed:

$$\text{pfd} = -182 + 0.5 \cdot \theta \quad \text{for} \quad \theta \le 10$$
$$\text{pfd} = -177 \quad \text{for } 10 < \theta \le 90$$

where θ is the angle of arrival, measured in degrees and the pfd is expressed in units of dB($W/m^2/MHz$). This will be met by reducing power, ceasing transmissions, or changing frequencies of AESs that would exceed the pfd criteria (see Attachment A).

3.5.1 The pfd levels given in Section 3.5 may be increased by 32 dB for the VLBA sites listed in Section 2.1.

3.6 Respond, as expeditiously as practicable, to an NSF request for protection in accordance with Sections 3.4 and 3.5 of any site listed in Section 2.1, for observations of special transient celestial objects (comets, supernovae, and other celestial objects of heretofore unknown type) that are not anticipated by the schedule of Section 3.7, and that may need to be accommodated on shorter notice. Requests for such observations are not expected to exceed 40 hours per calendar year.

NSF agrees to:

3.7 Maintain an observation schedule for the band 14.47 - 14.5 GHz for the sites listed in Section 2.1 and provide this schedule via both e-mail and fax, to the designated CBB point-of-contact address listed in Section 5.2 at least one week prior to the scheduled observations.

3.8 Provide, through NAIC and NRAO, full access to CBB representatives to data on interference that may be collected during observations that fall within the scope of this agreement.

4. Assignment and Termination

4.1 This agreement shall be binding upon the parties hereto and their respective successors and assigns.

4.2 This agreement may be terminated by mutual agreement of the parties, upon 6 months notice.

5 Points of Contact

5.1 Points of contact concerning this agreement.

Name: Dr. Tomas E. Gergely	Name: Karen Gielen
Organization: National Science Foundation	Organization: Connexion By Boeing
Title: Electromagnetic Spectrum Manager	Title: Executive Director International Regulatory Affairs
Address: 4201 Wilson Boulevard, Room 1030	Address: The Boeing Company 7755 East Marginal Way South Plant II - 2-25 Building M/C 14-08
City State Zip: Arlington VA 22230	City State Zip: Seattle, WA 98101
Phone: (703) 292-4896	Phone: (206) 655-5170
Fax: (703) 292-9034	Fax: (206) 655-5294
E-mail: tgergely@nsf.gov	E-mail: karen.n.gielen@boeing.com

5.2 Contacts concerning the notification of radio astronomy observation schedules:

Dr. Harvey Liszt	Name: Manager
Title: Director, Spectrum Management	Title: Network Operations Center
Organization: NRAO	Organization: CBB
Address: NRAO 520 Edgemont Road Charlottesville, VA 22903-2475	Address: The Boeing Company MC 83-26 P.O. Box 3707 Seattle, WA 98124-2207
Phone 434.296.0344	Phone: (253) 773-0609
Fax: 434.296.0278	Fax: (253).773-6632
E-mail: hliszt@nrao.edu	E-mail: connexion.noc@boeing.com

6 Signatures

This Agreement is being made in good faith by both parties and is effective on the date on which the last party signs it. It may be executed in one or more counterparts, each of which will be deemed an original and all of which together will constitute one and the same instrument.

For the National Science Foundation

By: [signature]

Name: Dr. Tomas Gergely

Title: Electromagnetic Spectrum Manager

Date: March 8, 2004

For Connexion By Boeing[SM]

By: [signature]

Name: Maureen C. Rinehardt

Title: CBB Contracts Manager

Date: March 8, 2004

Attachment A

Operational, Frequency and Geographical Avoidance Approaches to Meet the Radio Astronomy Protection Criteria

1 ITU-R Recommendation 769 Criterion

NSF has provided Boeing with two interference protection requirements for the radio astronomy telescopes. The first of these deals with the interfering signal power that would equal the spectral power flux-density interference threshold given in Table 2 of Recommendation ITU-R RA.769.

Frequency Band (GHz)	Interference Threshold Limit Spectral PFD	Sites
14.47 – 14.5	-221 dB(W/m^2/Hz)	Arecibo, Green Bank, Socorro

The maximum pfd produced by CBB AES at various altitudes is given in Figure 1, assuming a maximum EIRP of 46.2 dBW and an antenna mask based on measured data. Any improvements in the antenna mask or reductions in the maximum power level would result in improved pfd curves, which would improve the sharing situation.

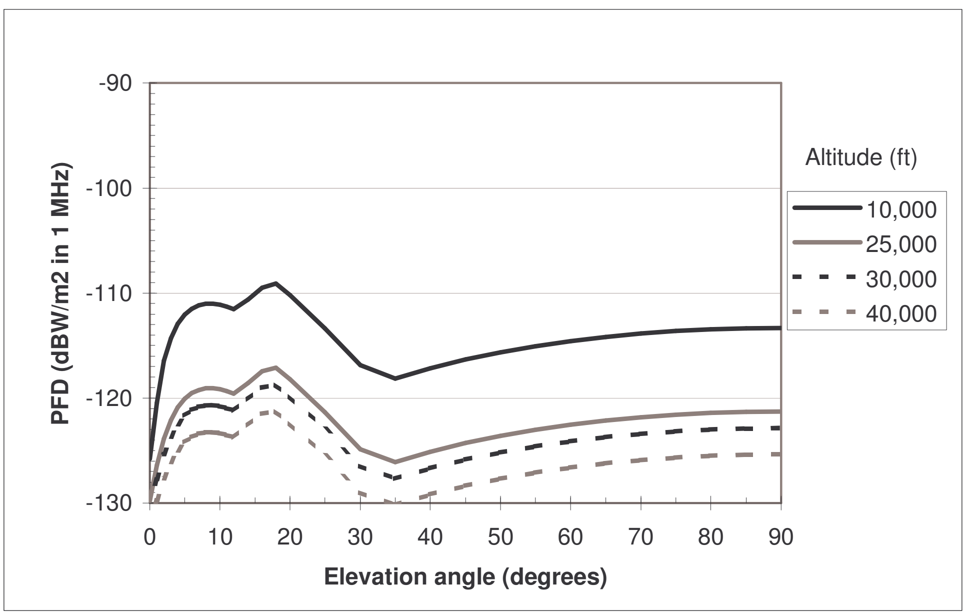

Figure 1. Maximum Power Flux Density from a CBB AES

Aggregate interference due to the emissions of a large number of AMSS aircraft will enter the RA observatory antenna at off-axis angles up to 180 degrees. To be compatible with the

RA system, the aggregate interference level would need to be kept below the -221 dBW/m^2/Hz level of the Recommendation ITU-R RA.769.

From Figure 1 above, the maximum pfd for an AMSS Aircraft is given as -109 dBW/m^2/MHz, however, this does not represent typical operation. A more typical case that might be considered as the average, would be an aircraft above 9.1 km (30,000 feet) operating at a data rate of 128 kbps and visible at a 5 degree elevation angle.

Using this maximum pfd, and using Green Bank as a typical radioastronomy observatory site, leads to the following maximum permissible pfd:

Maximum PFD for 9.1 km altitude (1 024 kbps)	-117.0 dBW/m^2/MHz
Average PFD for 9.1 km altitude (128 kbps)	-126.0 dBW/m^2/MHz
Bandwidth ratio (1Hz/MHz)	-60.0 dB
300 aircraft (dB) (Figure 4-7, Doc. WP7D/70)	24.8 dB
Aggregate spectral pfd	-161.2 dBW/m^2/Hz
Spectral pfd criteria (Table 2, Rec. ITU-R RA.769)	-221.0 dBW/m^2/Hz
margin	-59.8 dB
Bandwidth rejection required	59.8 dB
Maximum permissible pfd	-176.8 dBW/m^2/MHz

This indicates that about 60 dB of spectrum attenuation would be required to meet the RA spectral pfd criteria of Recommendation 769. Figures 4-1 through 4-4 of Document WP7D/70 indicate that this level is readily achievable.

This value is conservative for a number of reasons:

- Figure 4-7 of Document WP7D/70 (Portions of Document WP7D/70 that are relevant to this agreement are included in Attachment B) indicates that the majority of aircraft are visible below 5 degrees elevation angle, and Figure 1, above, indicates that the PFD of AMSS aircraft falls off sharply below this angle.
- Many radio astronomy sites have some degree of blockage on their horizon. This would eliminate the interference effects of aircraft which would be above the theoretical 4/3 Earth horizon but below the actual visible horizon.
- The 300 aircraft shown in Figure 4-7 of Document WP7D/70 includes many smaller aircraft that could not support an AMSS system.
- The method of calculating the number of aircraft was deliberately conservative. Rather than the number of aircraft visible simultaneously, the 300 aircraft actually represent the number of aircraft visible within a 5 minute period.

On this basis, the following pfd mask for individual AMSS AES un-wanted emissions in the 14.47 – 14.50 GHz band would protect the radio astronomy service:

$$\text{pfd} = -182 + 0.5*\theta \quad \text{for} \quad \theta \le 10$$
$$\text{pfd} = -177 \quad \text{for} \quad 10 < \theta \le 90$$

where θ is the angle of arrival, measured in degrees and the pfd is expressed in units of dB(W/m^2/MHz). This form of a pfd mask meets the calculated pfd requirement while providing additional protection at angles less than 10 degrees elevation angle, where most of the interference can be expected to originate.

2 VLBA site interference criteria

The second interference protection criteria applies to radio astronomy sites used for VLBA observations.

Frequency Band (GHz)	**Interference Threshold Limit Spectral PFD**	**Sites**
14.47 – 14. 5	-187 dB(W/m^2/Hz)	VLBA sites

Following the same approach as used above, a maximum permissible pfd can be calculated.

Maximum PFD for 9.1 km altitude (1 024 kbps)	-117.0 dBW/m^2/MHz
Average PFD for 9.1 km altitude (128 kbps)	-126.0 dBW/m^2/MHz
Bandwidth ratio (1Hz/MHz)	-60.0 dB
300 aircraft (dB) (Figure 4-7, Doc. WP7D/70)	24.8 dB
Aggregate spectral pfd	-161.2 dBW/m^2/Hz
Spectral pfd criteria (Table 2, Rec. ITU-R RA.769)	-187.0 dBW/m^2/Hz
margin	-25.8 dB
Bandwidth rejection required	25.8 dB
Maximum permissible pfd	-142.8 dBW/m^2/MHz

This indicates that about 26 dB of spectrum attenuation would be required to meet the RA spectral pfd criteria for VLBA sites. Figures 4-1 through 4-4 of Document WP7D/70 indicate that this level is readily achievable.

Attachment B

Appropriate Portions of Document ITU-R WP7D/70

WORKING DOCUMENT TOWARDS CPM TEXT REGARDING SHARING BETWEEN THE AMSS AND THE RADIO ASTRONOMY SERVICE IN THE 14-14.5 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 (WRC-2000) in turn invites the 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 meeting following WRC-2000 assigned to WP 8D the primary responsibility for preparation of draft CPM text relating to Agenda item 1.11 and Res. 216, several other ITU-R working parties and study groups (including SG 7) were requested to contribute studies in the area of their expertise. The band 14.47-14.5 GHz is allocated to the Radio Astronomy Service (RA) on a secondary basis.

2 Previous work

The May 2000 meeting of Working Party 7D received 4 documents addressing Agenda item 1.11: Documents 7D/31, 7D/34,7D/39 and 7D/46. As a result of these inputs, WP 7D developed a liaison statement regarding the Aeronautical Mobile-Satellite Service (AMSS) to WP 7E (Document WP 7E/21) which stated:

"WP 7D's preliminary findings show that AMSS systems could share on a secondary basis with the RAS in the 14.0-14.5 GHz band, provided that:

"a) AMSS stations do not transmit in the 14.47-14.5 GHz band within line-of-sight of radio astronomy stations operating in this band; and

"b) AMSS 14.47 band, within line-of-sight of radio astronomy stations during radio astronomy observations are attenuated to meet Recommendation ITU-R RA.769 limits within the 14.47-14.5 GHz band. Attenuations in the range

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

65 to 71 dB may be required to meet these limits, depending on aircraft altitude. Such attenuations may be met by the AMSS transmitter through a combination of reduced signal power, and maintaining adequate frequency separation between the AMSS aircraft transmissions and the 14.47-14.5 GHz band. In coordinating stations of the RAS and the AMSS, account should be taken of RR S5.31 that states that stations of a secondary service "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".

"WP 7D's preliminary findings are based on analytically derived antenna patterns and out-of-band spectra, and no consideration of air-traffic information. These studies will be completed by the consideration of measured antenna patterns, measured out-of-band spectra and relevant air-traffic information, for the October 2001 meeting of WP 7E. WP 7E will prepare draft CPM text to be forwarded to WP 8D."

This document provides the data requested by WP 7D and extends the studies to incorporate them. The data dealing with: AMSS antenna radiation patterns, AMSS out-of-band emissions and air traffic routes are discussed in section 4. This paper discusses these topics with respect to a specific RA site in Green Bank WV, USA to determine if coordination of AMSS and RA systems is feasible. A similar approach could be followed for RA sites with different characteristics.

3 Radio Astronomy characteristics

The following tables summarize some of the important RA characteristics from Recommendation ITU-R 769-1.

TABLE 3-1

Radio Astronomy Parameters used

Relevant RA Telescope Parameters	Value
Frequency Band	14.47-14.5
Antenna size (m)	25 to 100
Antenna efficiency	64 %
Antenna radiation pattern	RR Appendix 7
Observation Time (typical)	2000 sec
Interference criterion	Recommendation ITU-R RA.769-1

TABLE 3-2

Radio astronomy telescopes having capability for spectral line measurements in the 14.47 to 14.5 GHz band

Observatory	Location	Latitude	Longitude	Telescope	Diameter	Frequency Band (GHz)
NRAO	Green Bank, W.Va.	38^0 25' N	79^0 50' W	Paraboloid	100 m	12-15.4
NRAO	New Mexico	34^0 04' N	107^0 37'W	VLA; 27 shaped paraboloids	25 m each antenna	14.4-15.4
NRAO	Several: NM,AZ,NTX, IA,WA,CA,VI ,HI,NH	Several	Several	VLBA; 10 shaped paraboloids	25 m each antenna	14.4-15.4
Australian National Radioastronom y Observatory	Parkes, Australia	32^0 59' S	148^0 15'E	Steerable Paraboloid	64 m	12.5-15.5
Ceduna RA Observatory	Ceduna, Australia	31^0 52' S	133^0 48' E	Steerable paraboloid	30m	1.6-24
Effelsberg Radio Observatory	Germany			Steerable paraboloid	100m	
Cambridge Radio Observatory	UK					
Ratan-600 Astrophysica Laboratory	Zelenchukska ya, Russian Federation	$43^0$50	$41^0$35	Variable profile antenna' circle of 895 reflector elements	600 m	14.4
Puschino FIAN	Puschino FIAN, Russian Federation	$54^0$49	$37^0$40	Steerable paraboloid	22m	14.4
Nobeyama Radio telescope	Nobeyama, Japan	35^0 54	136^0 00	Steerable paraboloid	45 m	13.5-15.5

TABLE 3.3

Threshold levels of interference detrimental to radioastronomy spectral-line observations

Frequency (MHz)	Assumed spectral line channel bandwidth (kHz)	Minimum antenna noise temperature (K)	Receive noise temperature (K)	Threshold Interference Level Input power (dBW)
14 500	150	15	30	-214

4 Additional AMSS characteristics

Table 4-1 summarizes the AMSS systems parameters as discussed in the previous reports. The following three subsections address measured antenna patterns, un-wanted emissions spectra and air traffic information, as requested in Document WP 7E/21.

TABLE 4-1

AMSS System Parameters

Parameters	Units	System Parameters
Operational		
Frequency Band	GHz	14-14.5
Altitude	meters	< 12,100
Mainbeam EIRP (per carrier)	dBW	48.0, 1 024 kbps (max) 39.0, 128 kbps (nominal) 30.0, 16 kbps (min)
Mainbeam EIRP density in 1 MHz	dBW/MHz	33.7, 1 024 kbps (max) 24.7, 128 kbps(nominal) 15.7, 16 kbps (min)
Mainbeam EIRP density in 1 kHz	dBW/kHz	3.7, 1 024 kbps (max) -5.3, 128 kbps(nominal) --14.3, 16 kbps (min)
Signal bandwidth	MHz	27 (constant for all data rates)
Aircraft pitch angle	deg	0 to 5^0
Aircraft bank angle	deg	0 to 10^0
Spatial		
Antenna diameter	m	0.38
Antenna beam width @ 0^0 scan	deg	3.3^0 x 3.5^0
Antenna gain @0^0scan	dBi	33.3
Antenna Patterns		See Annex B
Spectral		
Waveform type		Direct sequence spread spectrum and O-QPSK modulation, and square root raised cosine filtering
Spectral mask		See Section 4.2
# of simultaneous carriers through the airborne antenna		1

4.1 AMSS unwanted emissions

The AMSS transmitted signal has a bandwidth of 27 MHz, 90% of the 30 MHz transponder bandwidth. Tests were performed of the spurious and out-of-band emissions of the aircraft transmitter to determine the effect that the AMSS system might have on systems operating on frequencies adjacent to the AMSS signal The measurements were performed on the output of the phased array antenna. The transmit antenna system incorporates filtering in three locations:

- Raised cosine filtering of the baseband waveform.
- 14.0 to 14.5 GHz bandpass filter at the output of the upconverter.
- Notch filter in the 14.47 to 14.5 GHz band placed between the output of the driver amplifier and input to the array antenna.

Figure 4-1 shows the waveform spectrum at maximum power level with a center frequency of 14.4 GHz. The effect of the notch filter is clearly seen in this Figure. The overall spectral attenuation in the 14.47 to 14.5 GHz band is greater than 65 dB. Figures 4-2, 4-3, and 4-4 each provide spectra of the waveform at the array antenna transmit beam over a frequency range from 13.75 to 14.50 GHz. The flat line in each figure at –98 dBW/kHz represents the spectrum analyzer noise floor. The center frequency of the AMSS transmission was centered at 14.4 GHz. The graphs differ in the transmitted EIRP to show the effect of AMSS power reductions on the curves. The measurements in Figure 4-1 were made using the maximum operating EIRP from the antenna. while the measurements in Figures 4-2 to 4-4 were made with transmitting at 5, 7 and 10 dB below the maximum operating level. The Figures show data as measured from a receive horn antenna located in the far field of the transmit antenna. The EIRP spectral density of the transmit antenna can be extrapolated from the spectral data in the Figures 4-2 to 4-5 by raising the waveform spectral curve by 63 dB.

The figures indicate that the out-of-band attenuation in the 14.47-14.5 GHz band at a transmit power greater than 5 dB below saturation is more than 70 dB relative to the maximum AMSS power level. The attenuation may exceed this value, but the spectrum analyzer noise floor masks radiated emissions from the antenna lower than this. The spectral measurements show that a notch filter located at the array input can provide significant attenuation of unwanted emissions to protect the radio astronomy observations.

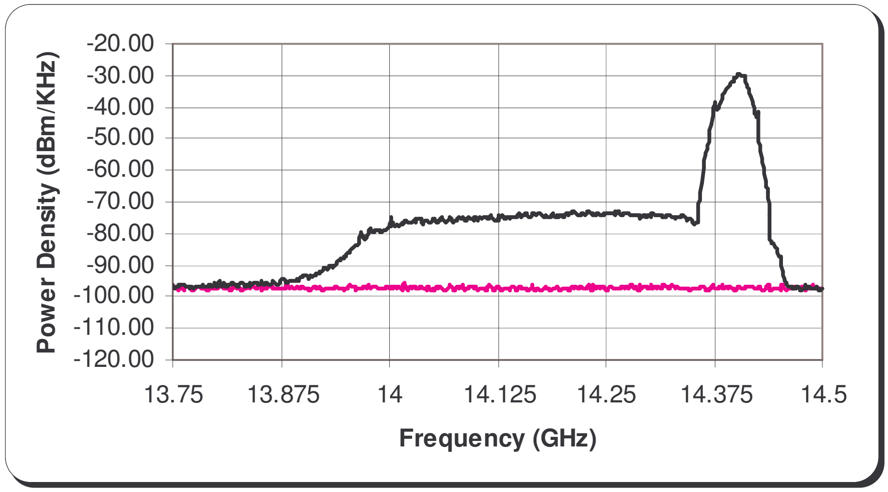

FIGURE 4-1

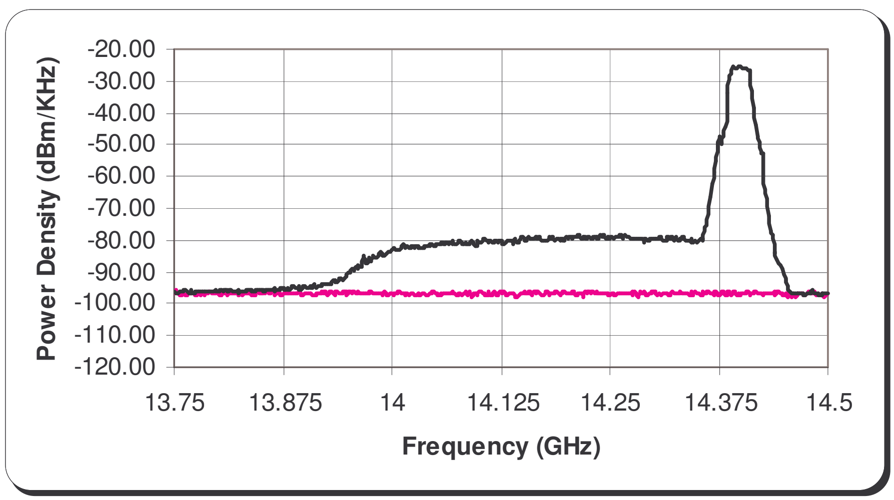

FIGURE 4-2

Measured AMSS radiated spectrum operating at 5 dB below maximum

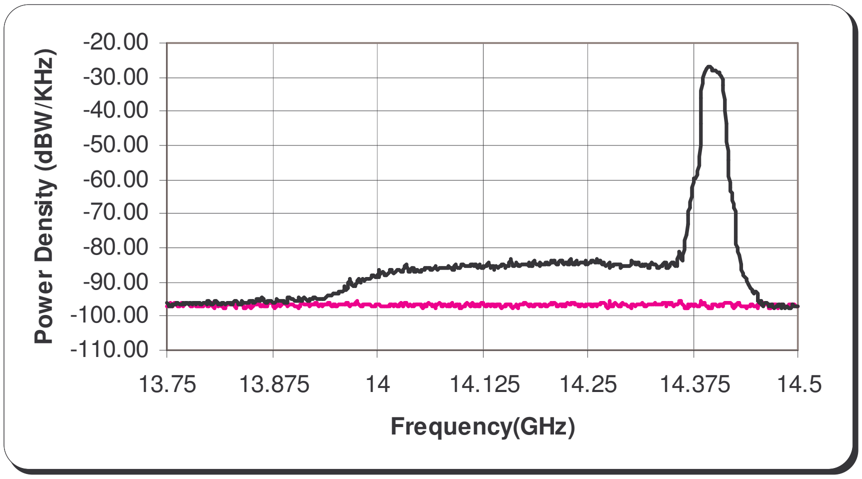

FIGURE 4-3

Measured AMSS radiated spectrum at 7 dB below maximum

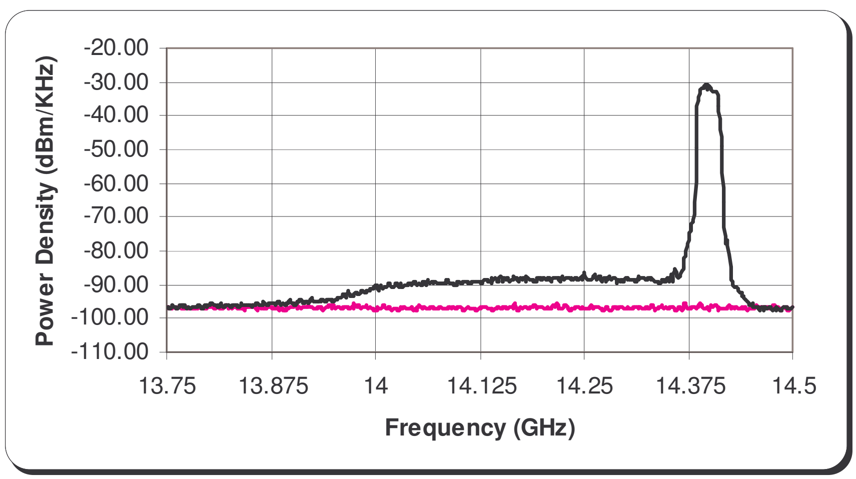

FIGURE 4-4

Measured AMSS radiated spectrum at 10 dB below full rated EIRP

4.2 AMSS Antenna radiation pattern

Annex B contains the results of flight tests performed to collect data on the AMSS aircraft antenna relative sidelobe and backlobe gain. This information was used to develop a modified antenna gain mask for use in interference calculations. Figure 4-5 shows the modified mask as well as the mask used in previous analyses. The area of the mask that is critical for most interference situations is the area near 90 degrees. The difference between the previous mask and the modified mask is relatively small in this area.

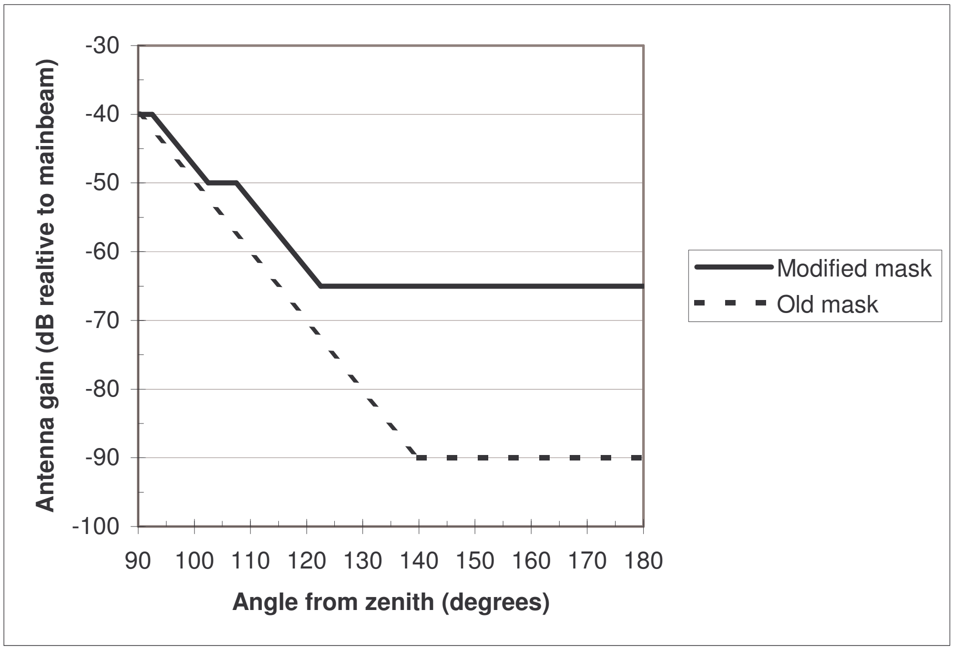

FIGURE 4-5

New and modified AMSS antenna gain masks

In analyzing the effects of AMSS aircraft emissions on RA, it is useful to express the emission level produced in terms of a pfd level at the Earth's surface. This approach removes some of the variability due to aircraft altitude inherent in analysing the potential interference situation, thereby simplifying the analysis. It is also a desirable approach for the AMSS, because the data rates, and therefore emitted power levels, will generally increase with altitude.

Figure 4-6 shows the maximum pfd levels that could be emitted by AMSS aircraft, corresponding to a data rate of 1 Mbps. The top curve is for an altitude of 3.1 km (10,000 feet), which represents a very low altitude for the type of aircraft that would use an AMSS system. The other curves from 7 km (25,000 feet) curve represents a low cruising altitude while the 9 and 12 km curves bracket the normal cruising altitudes.

The effect of various pfd levels on the RA observatories will be investigated in Section 5.

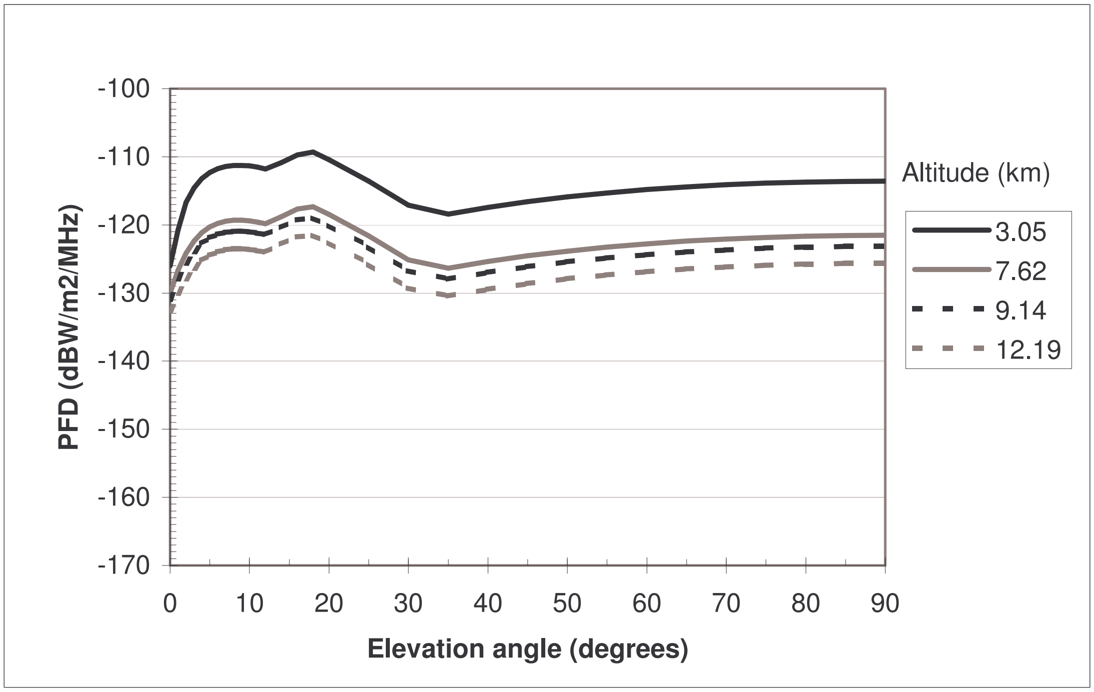

FIGURE 4-6

Maximum pfd produced by AMSS aircraft

4.3 Air traffic patterns

The levels of interference received by an RA station will depend, *inter alia*, on the number of AMSS aircraft in the vicinity of the Earth station, and particularly on the number of aircraft near the mainbeam of the radio astronomy antenna.

Figure 4-7 shows a graph of the number of aircraft visible to Green Bank, WV in the U.S. on 27 September 2000 as a function of the time of day. The graph contains five separate curves, corresponding to five different elevation angle ranges. The curve overstates the number of potential AMSS aircraft because it includes all commercial aircraft, and not just those large enough to carry AMSS. It also includes short duration flights during which passenger use of the AMSS system would not be feasible.

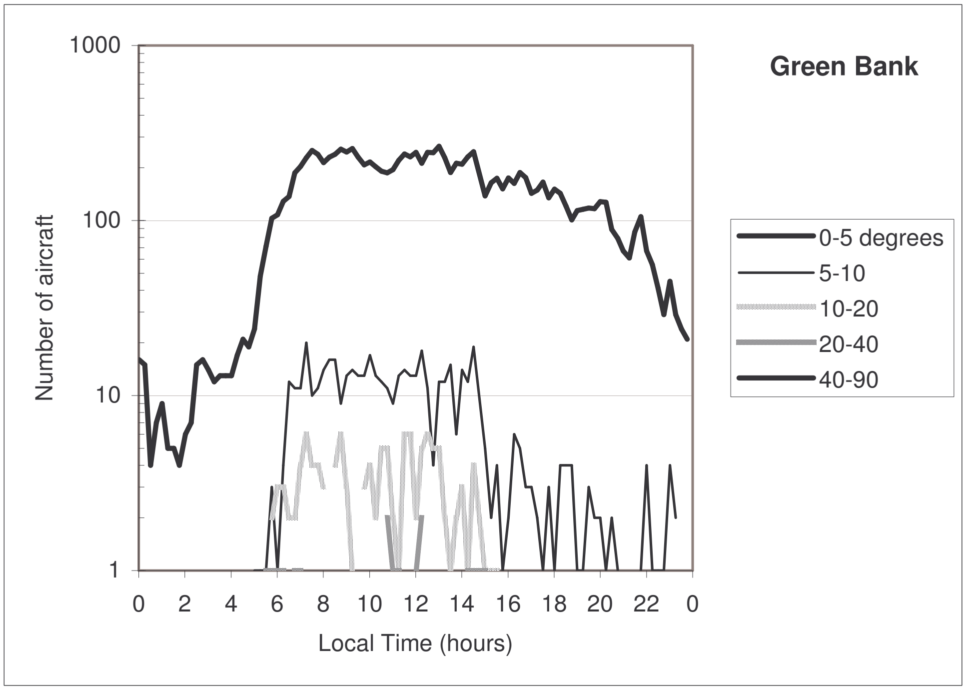

FIGURE 4-7

Number of aircraft visible to Green Bank

5 Continuation of analysis

Interference into the RA observatory occurs primarily when an AMSS aircraft crosses through or near the mainbeam of the RA antenna as shown in Document WP 7D/39. An approach to controlling interference between the aircraft and the earth station would be to place a very restrictive limit on AMSS emissions when the aircraft is in the vicinity of the RA observatory during observation times. This approach is feasible because of the positive control of AMSS aircraft emissions by the AMSS Network Control Center (NCC).

The problem of identifying constraints on the AMSS such that the RA stations are protected from interference can be addressed in two parts, based on the relative location of the aircraft relative to the observatory. The first is the effect of aircraft in or near the mainbeam of the RA station antenna. The second addresses the aggregate effect of aircraft in the back lobes and far side lobes of the RA antenna.

Figure 5-1 is a graph of the antenna gain mask for RA antennas of 25, 64 and 100 m diameter.

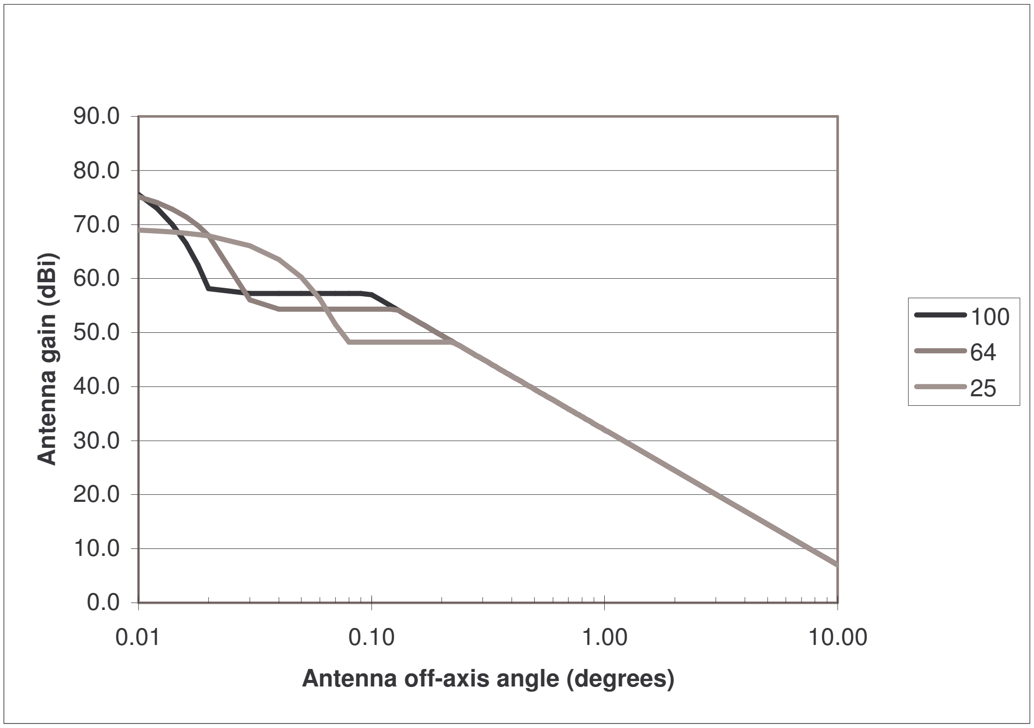

FIGURE 5-1

RA observatory antenna gain (100 m, 64 m and 25 m)

5.1 Near mainbeam discussion

The protection requirements of the radio astronomy service can be stated independent of the antenna and power levels of the AMSS aircraft. Document WP 7D/39 calculates a level of attenuation in the 14.47 to 14.5 GHz band of the AMSS signals required to meet the RA criteria of Recommendation ITU-R RA.769. Table 4-3 from that document is provided below.

TABLE 5-1

Spectral attenuation (dB) required to meet radioastronomy criteria (Document 7D/39, Table 4-3)

		Aircraft Altitude (ft)			
		10 000	15 000	20 000	30 000
RA antenna Elevation angle (degrees)	5	-70.2	-68.4	-67.2	-65.1
	10	-66.0	-64.2	-63.0	-61.1
	20	-57.7	-56.0	-54.7	-52.9
	60	-26.5	-24.7	-23.4	-21.3
	90	-29.4	-26.9	-25.1	-22.8

In Figure 5-2, this required attenuation level has been subtracted from the AMSS PFD that produced it, resulting in an equivalent pfd criteria curve that exactly meets the RA criteria of Recommendation ITU-R RA.769. This PFD criteria curve does not depend on the AMSS RF characteristics, but does depend on the aircraft altitude and speed. It also varies with the RA antenna elevation angle as the original table in WP 7D/39 does. The curves have also been converted from the RA reference bandwidth of 150 kHz to a reference bandwidth of 1 MHz to make them consistent with the previous figures. Also, additional points have been calculated to complete the curves

The curves are less restrictive at higher elevation angles because the probability of being near the mainbeam of the antenna goes down very sharply.

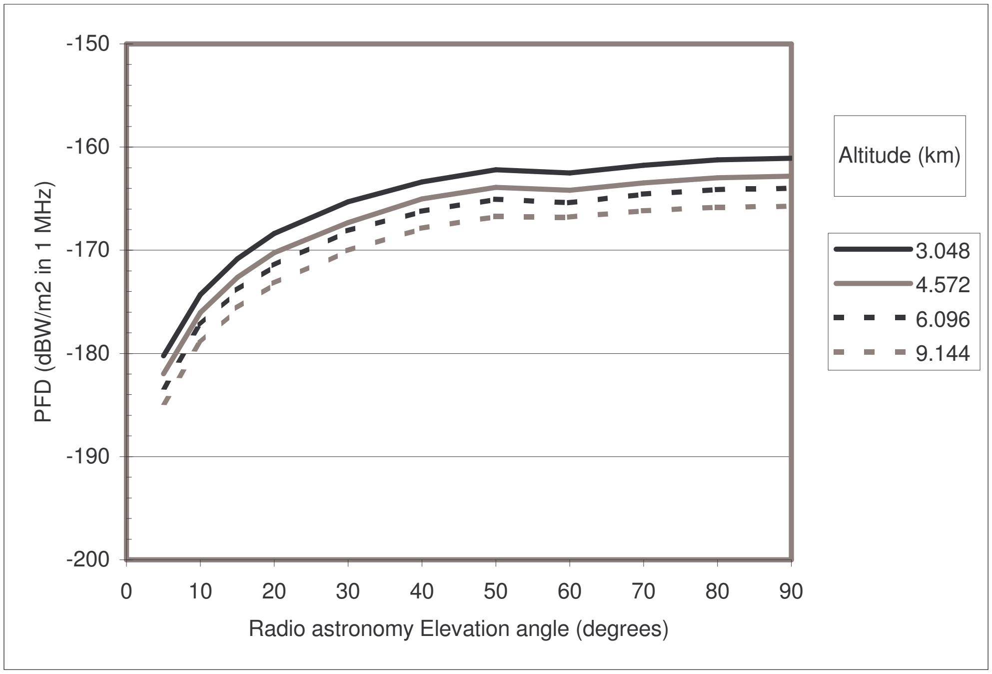

FIGURE 5-2

Critical pfd levels for radioastronomy

The critical pfd curves in Figure 5-2 can be compared to the curves showing the pfd produced by AMSS in Figure 4-6. To be compatible with the radio astronomy service, the AMSS pfd curves of Figure 4-6 must be attenuated until they are below the criteria pfd curves of Figure 5.2. Because of the shape of the curves, it is apparent that the minimum separation between the curves occurs at 5 degrees elevation angle. That is, the maximum, in-band pfd levels at 5 degrees elevation of -112 to –124 dBW/m^2/MHz (Figure 4.4) must be reduced to -185 dBW/m^2/MHz as shown in Figure 5-2. The worst case attenuation requirements range from 61 to 73 dB, depending on altitude. As shown in section 4.0, these attenuation levels can be supported by appropriate reduction of the AMSS signal EIRP below its maximum value. From the worst case standpoint, a modest 5 to 10 dB back off from maximum EIRP will ensure that the AMSS unwanted emissions are reduced to levels necessary to provide adequate protection to the RA observations when the AMSS center frequency is 14.4 GHz or below.

These power back-off levels are consistent with the AMSS operating power levels when supporting normal data rates.

5.2 Far sidelobe and back lobe discussion

Aggregate interference due to the emissions of a large number of AMSS aircraft will enter the RA observatory antenna at off-axis angles up to 180 degrees. To be compatible with the RA system, the aggregate interference level would need to be kept below the -214 dBW/150 kHz level of the Recommendation ITU-R RA.769.

Since the emissions of a large number of AMSS aircraft may enter the RA antenna at a wide range of azimuths, it can be assumed that that average antenna gain for the RA antenna is 0 dBi. From Figure 4-4 above, the maximum pfd for an AMSS Aircraft is given as –112.2 dBW/m^2/MHz, however, this does not represent typical operation. A more typical case that might be considered as the average, would be an aircraft above 9.1 km (30,000 feet) operating at a data rate of 128 kbps and visible at a 5 degree elevation angle.

Using this maximum pfd, and the average RA antenna gain leads to the following interference level:

Nominal PFD for 9.1 km altitude	-124.3 dBW in 1 MHz
Area of an isotropic antenna	-44.4 dBm^2
Average RA antenna gain	0.0 dBi
Out-of-band rejection	70.0 dB
Bandwidth ratio (150 kHz/MHz)	-8.2 dB
Interference	-246.9 dBW in 150 kHz
Interference criteria	-214.0 dBW in 150 kHz
margin	32.9 dB
Equivalent number of aircraft	1950

This indicates that more than 1950 AMSS aircraft simultaneously visible to the RA Earth station would be needed to exceed the RA interference criteria. This number could be further increased since Figure 4-7 indicates that the majority of aircraft are visible below 5 degrees elevation angle, and Figure 4-6 indicates that the PFD of AMSS aircraft falls off sharply below this angle. Figure 4-7 indicates that only about 300 aircraft can be expected to be simultaneously visible to the RA observatory, and this includes many smaller aircraft that could not support an AMSS system.

6 Conclusions

The RA Service operates at a relatively few sites and uses antennas with a gain greater than 65 dBi. The main mechanism for interference occurs when an aircraft using an AMSS system is visible in or near the mainbeam of the RA antenna. The probability of being near the mainbeam of an RA antenna is extremely low. In such a situation, coordination between the two systems is the most appropriate method for ensuring compatibility.

This study indicates that coordination agreements between AMSS and Radio Astronomy observatories can be developed based on controlling the emissions levels of the AMSS aircraft in the 14.47-14.5 GHz band when operating in the vicinity of the RA observatory during observations. This essentially means that the AMSS aircraft must avoid the RA band and provide appropriate filtering to provide desired out-of-band attenuation when the observatory is in operation. Such emissions restrictions are feasible for the AMSS because of the positive control maintained by the AMSS Network Control Center.

ANNEX A

(NOT INCLUDED)

ANNEX B

Antenna Sidelobe/Backlobe Flight Test Data

WP 7B and WP 7D both requested that antenna measurements be performed to confirm the analytically derived antenna radiation diagrams provided in previous documents. To confirm this data, the 873-element phased array antenna was mounted and flown on a Boeing 737-400 Aircraft in order to collect ground received field strengths as a function different elevation and azimuth angles. The aircraft was flown at Moses Lake, which is about 150 miles east from Seattle, Washington in the United States. Figure 1 shows the tracks used by the aircraft for collecting data. The aircraft altitude and other relevant antenna beam scan parameters for each track are given in the Table 1. The peak EIRP from the antenna was set at 27 dBW.

The received signal levels were processed to calculate antenna sidelobe/backlobe levels as a function of elevation and azimuth angles with respect to the antenna centered spherical coordinate system.

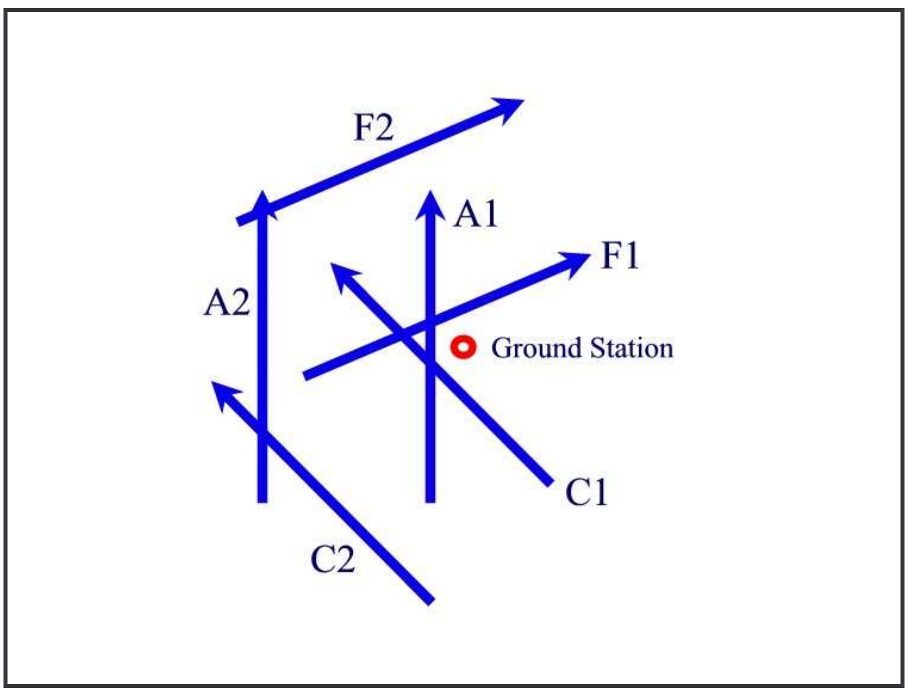

FIGURE 1

Aircraft tracks and designations used during flight testing

For Route 101 to 106, the shortest horizontal separation between the test track and the TM Van station is 4.9 km. For Routes 201 to 206, the shortest horizontal separation between the test track and the TM Van station is 29.5 km).The track length is 46.3 km for all conditions except Route 401.

All tracks except the last one shown in the Table 1 provide crossing flight conditions relative to the receive antenna beam. The last track (Route 401) shown in the Table 1 provides in-line (flying straight towards) condition.

The results of the flight tests are shown in Figures 3 and 4. In these figures, 90 degrees is the horizontal plane and 180 is straight down below the aircraft. Figure 3 summarizes the calculated AMSS aircraft antenna gain as a function of the off zenith angle. For the flights in this figure, the AMSS antenna beam was pointed 45 degrees from zenith, or 45 degrees above the horizontal plane. Also shown in the figure is the antenna mask derived previously from analytical data.

The measured data in Figure 2 shows the shielding effectiveness of the aircraft body. The backlobe levels are well below –60 dB relative to the peak of the beam.

Figure 3 provides the a graph of similar flight data, but in this case, the antenna is pointed 60 degrees from zenith, near the lowest elevation angle for the system of 63 degrees. As can be seen, the test data exceeds the original antenna mask in several areas. The pfd mask was therefore adapted to reflect this new data. The new antenna mask is also plotted over the data in Figures 2 and 3.

The points defining the revised antenna mask are as follows:

Angle from zenith (degrees)	**Antenna gain, relative to mainbeam**
90	-40
92.5	-40
102.5	-50
107.5	-50
122.5	-65
180	-65

TABLE 1

Aircraft Test Flight Conditions

TEST CONDITIONS					Flight Start		Flight End		Pointing angle	
Route	Alt	EIRP	Track	Head.	I.D.	Lat/Long	Lat/Long	I.D.	Azimuth	Elevation
101	15000 ft	27 dBW	A1	360 T	A11	N4700.3 W11924.2	N4725.3 W11923.5	A12	0	45
102			C1	315 T	C11	N4702.1 W11909.7	N4719.8 W11935.7	C12	-45	45
103			F1	067 T	F11	N4710.4 W11938.4	N4720.1 W11904.5	F12	67	45
104			A1	360 T	A11	N4700.3 W11924.2	N4725.3 W11923.5	A12	0	60
105			C1	315 T	C11	N4702.1 W11909.7	N4719.8 W11935.7	C12	-45	60
106			F1	067 T	F11	N4710.4 W11938.4	N4720.1 W11904.5	F12	67	60
201	10000 ft	27 dBW	A2	360 T	A21	N4700.3 W11943.7	N4725.3 W11943.1	A22	0	45
202			C2	315 T	C21	N4652.7 W11923.6	N4710.4 W11949.5	C22	-45	45
203			F2	067 T	F21	N4722.6 W11946.1	N4732.4 W11912.1	F22	67	45
204			A2	360 T	A21	N4700.3 W11943.7	N4725.3 W11943.1	A22	0	60
205			C2	315 T	C21	N4652.7 W11923.6	N4710.4 W11949.5	C22	-45	60
206			F2	067 T	F21	N4722.6 W11946.1	N4732.4 W11912.1	F22	67	60

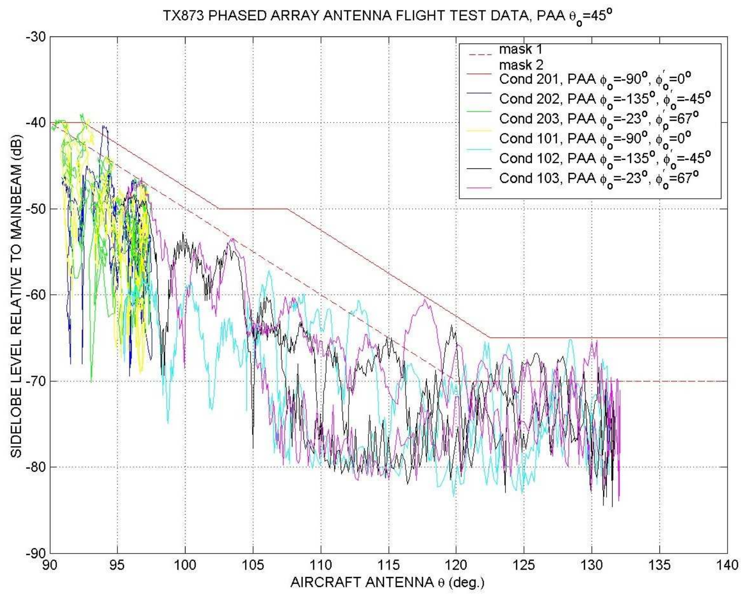

FIGURE 2

Antenna backlobe measurements as a function of elevation angle from zenith and for various azimuth cuts with antenna beam scanned to 45 deg from zenith

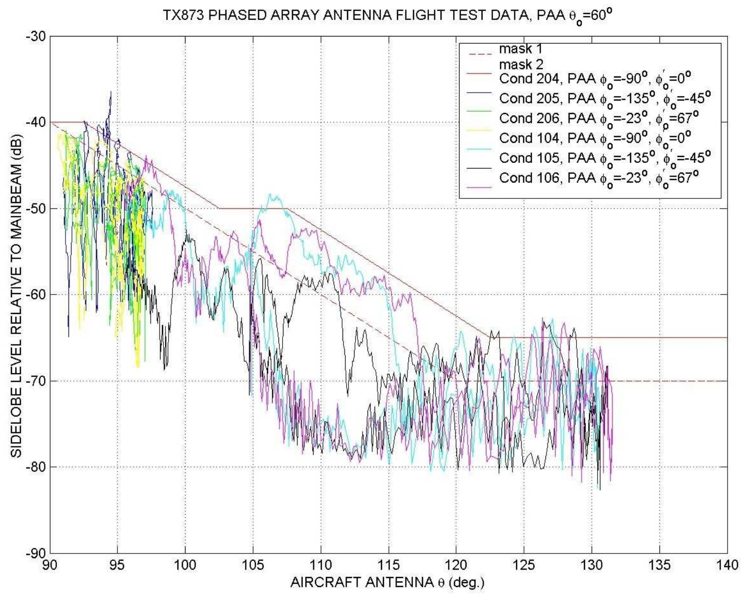

FIGURE 3

Antenna backlobe measurements as a function of elevation angle from zenith and for various azimuth cuts with antenna beam scanned to 60 deg from zenith