TECHNICAL APPENDIX

On December 21, 2001, The Boeing Company ("Boeing") was authorized by the Commission to operate pursuant to a blanket license (Call Sign E000723) up to 800 technically identical transmit and receive aircraft earth stations ("AESs") using phased array antennas (Form 312 antenna ID: ATR-1A) and operating with the Telstar 6 satellite in the 14.0-14.5 GHz and 11.7-12.2 GHz bands in the United States, including the airspace above its territorial waters, subject to certain conditions.[1] Subsequently, Boeing requested and was granted authority to add the SES Americom AMC-4 satellite as an additional point of communication.

The instant application requests authority, among other things, to modify that license to substitute 675 reflector antenna AESs (Form 312 antenna ID: ATR-1B) for a similar number of phased array antenna AESs, resulting in a modified blanket license for 125 phased array antenna AESs and 675 reflector antenna AESs (800 total). Adding the reflector antenna AESs to the Connexion by Boeing[SM] system will allow Boeing to better serve its commercial, government, and business customers by enabling operation at the low elevation angles required for high latitude flights.

1 Interference Conditions in Transmit-Receive Order Remain Unchanged

Boeing hereby acknowledges that it will continue to operate both its licensed phased array and new reflector antenna AESs in full conformance with the express conditions contained in paragraphs 19 and 20 of the *Transmit-Receive Order*. In particular, Boeing will operate its reflector antenna AESs such that the aggregate off-axis E.I.R.P. levels produced by all co-frequency AMSS terminals are no greater than the interference levels that have been accepted by adjacent FSS satellite systems in coordination with the aforementioned satellites.

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[1] *See The Boeing Company*, Order and Authorization, DA 01-3008, File No. SES-LIC-20001204-02300 (Int'l Bur./OET rel. Dec. 21, 2001) ("*Transmit-Receive Order*").

Boeing further confirms that the requested modifications will have no adverse impact on other authorized users of the Ku-band. The reflector antenna AES will continue to meet the stated levels necessary to protect NASA TDRSS operations and Radio Astronomy stations as set forth in the applicable agreement and letter referenced in the *Transmit-Receive Order*.[2] Boeing's operations, as modified, also will comply with all of the conditions of the *Transmit-Receive Order*, including any relevant ITU-R Recommendations.

2 System Description as Modified by Application

The addition of reflector antenna AESs does not alter the fundamental operational characteristics of the licensed AMSS system. Reflector antenna AESs will operate simultaneously with phased array antenna AESs, will communicate with the same satellite transponders and will be controlled in the same way. Specifically, the requested modification will not result in any change to the operating parameters of the licensed system, including maximum off-axis E.I.R.P. and E.I.R.P. density, or otherwise increase the potential for harmful interference to any other authorized user. Included below is a description of the reflector antenna AES, its gain patterns, typical link budgets, and a discussion of compliance with the design guidelines set forth in the *Transmit-Receive Order*. Boeing hereby incorporates by reference all data items and answers to questions not changed by this modification application as set forth in Boeing's *Transmit-Receive Application*, as amended by subsequent supporting submissions in File Nos. SES-LIC-20001204-02300 and SES-MOD-20020308-00429.[3]

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[2] *See Transmit-Receive Order* at notes 20 & 21.

[3] *See Application of The Boeing Company for Blanket Authority to Operate up to Eight Hundred Technically-Identical Transmit and Receive Mobile Earth Stations Aboard Aircraft in the 11.7-12.2 and 14.0-14.5 GHz Frequency Bands*, File No. SES-LIC-20001204-02300 (December 4, 2000, supplemented January 10, 2001) ("*Transmit-Receive Application*").

3 Reflector Antenna AES Description

Reflector antenna AESs will transmit and receive using a single elliptical Cassegrain reflector that is mechanically steered to acquire and track the desired satellite through aircraft flight maneuvers and over a large geographic range. The polarization angle is electronically rotated to match the polarization of the satellite. The reflector antenna design and manufacturing has been subcontracted to Mitsubishi Electronics Company ("MELCO") and will be integrated by Boeing into its AES design. The reflector antenna will be mounted on the top of the aircraft and enclosed in a radome. Associated support electronics will be installed in the aircraft fuselage. Figure 1 below shows a rendering of the reflector antenna.

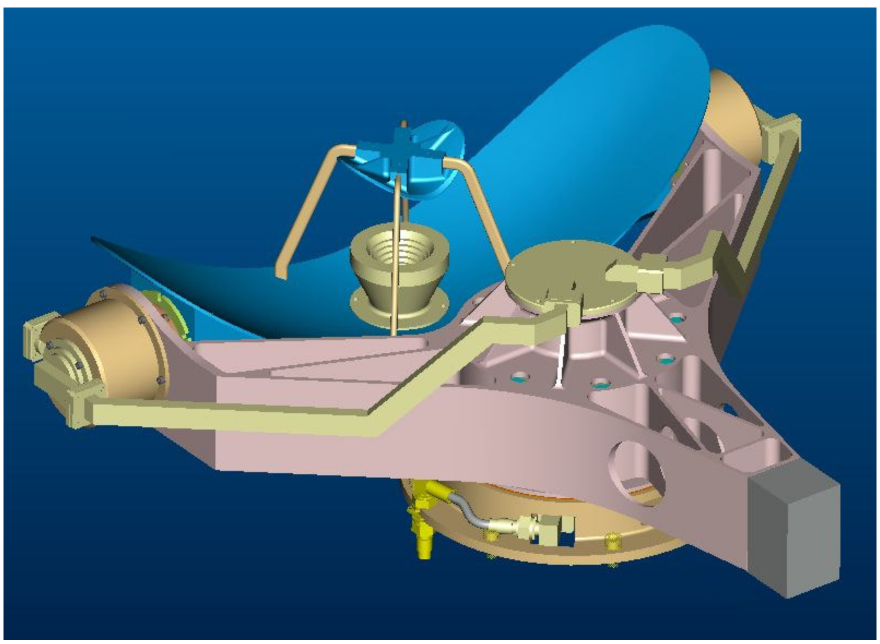

Figure 1: Reflector Antenna AES

The reflector antenna enables this AES to operate at the low elevation angles required for high-latitude flights. The reflector antenna AES can operate down to an elevation angle of 5º without any loss in directive gain. It does not suffer the gain loss with increasing scan angle that is inherent to phased array antennas and which limits their use at low elevation angles.[4] Additionally, without directive gain loss, the reflector antenna AES can provide the same transmit data rate with a lower maximum E.I.R.P. than the phased array antenna AES (46.7 dBW versus 51.2 dBW). Table 1 summarizes important characteristics of the reflector antenna AES.

Aperture Dimensions	65.0 cm x 19.6 cm elliptical
Antenna Beamwidth	2.0° × 6.2°
Transmit Band	14.0 GHz to 14.5 GHz[5]
Receive Band	11.7 GHz to 12.2 GHz[6]
Transmit Gain (on axis)	33.1 dBi at 14.2 GHz
Receive Gain (on axis)	31.6 dBi at 12.0 GHz
G/T	10.5 dB/K
Minimum Elevation Angle	5°
Antenna Polarization	Linear (rotatable)
Maximum Slew Rate - Azimuth	>24°/sec
- Elevation	>12°/sec

Table 1: Reflector Antenna AES Characteristics Summary

3.1 Reflector Antenna AES Pointing and Polarization Control

The reflector antenna AES is designed to achieve a pointing accuracy of 0.25° 1-sigma in the azimuth plane (which aligns roughly with the geostationary satellite orbit ("GSO") arc from mid to high latitudes) and 0.6° 1-sigma in the elevation plane (which is roughly perpendicular to the GSO arc from mid to high latitudes). The reflector antenna AES will maintain this pointing accuracy in the maximum dynamic environment of a commercial aircraft. This is approximately

[4] *Transmit-Receive Application* at 14.

[5] Boeing's blanket AMSS authorization permits its authorized AESs to transmit throughout the 14.0-14.5 GHz band and Boeing seeks to retain such operational flexibility. However, to protect radio astronomy stations, Boeing's AESs typically do not transmit in the upper 100 Megahertz of the band.

[6] The antenna is designed to receive across the entire 10.7 GHz to 12.75 GHz in contemplation of operations outside the United States, including in other ITU Regions with different spectrum allocated to Ku-band satellite downlinks. However, Boeing does not seek to operate outside the 11.7-12.2 GHz band within the United States.

6º/sec in roll and 2º/sec in pitch and yaw/heading while airborne, and 10º/sec in heading on the ground, which is well within the antenna slew rates noted in Table 1. If the reflector antenna AES ever exceeds the budgeted control error, it will automatically inhibit transmission.[7]

The initial acquisition of the satellite forward link is accomplished by means of open loop pointing and polarization control, through the use of the airplane navigation system and antenna rate gyro data; commanded satellite position; and estimated antenna alignment parameters.

Following initial acquisition, the antenna pointing is refined using a sequential lobing technique similar to the one described for the phased array antenna in the *Transmit-Receive Application*.[8] This sequential lobing technique provides a closed loop measure of antenna to satellite pointing performance, the results of which are used to update the antenna alignment parameters. As was demonstrated in Boeing's license compliance report,[9] this technique is resistant to being "pulled off" by adjacent satellites, as is required by ¶19(h)(2) of the *Transmit-Receive Order*. While the reflector antenna AES is performing sequential lobing, the transmit E.I.R.P. is restricted so that the off-axis E.I.R.P. limits continue to be satisfied.

After acquisition and initial sequential lobing, pointing is accomplished through a combination of open loop pointing and polarization control with periodic closed loop updates. Using this data, the pointing commands to the antenna servos are updated approximately 500

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[7] In the very unlikely event that the budgeted error is exceeded, the reflector antenna AES will still automatically inhibit transmission when it loses the forward link, as described in Boeing license application. *See Transmit-Receive Application* at 9.

[8] *See Transmit-Receive Application* at 24.

[9] *See Boeing AMSS System License Compliance Report*, File No. SES-LIC-20001204-02300 (August 19, 2002) at 8 ("Compliance Report").

times per second.[10] The use of high rate inertial data from the airplane navigation system and antenna rate gyros negates the need for the rapid sequential lobing used on the phased array.

Periodic closed loop updates to the alignment of the antenna to the airplane navigation system are performed approximately every ten to twenty minutes, by repeating the sequential lobing described above. This allows the system to account for changes in alignment that result from effects such as aircraft pressurization, fuel load, and flight state.

As described in Section 3.4.3, the pointing performance will be verified by testing, and the actual accuracies will be used in the network operations center ("NOC") when accounting for the variation in off-axis E.I.R.P. caused by mis-pointing.[11]

3.2 Reflector Antenna Patterns

Measured receive and transmit antenna gain patterns for the azimuth and elevation planes are shown in Figures 2 through 9. The gain patterns are shown for operation on both H-Pol and V-Pol.

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[10] This update rate is an order of magnitude faster than for the phased array antenna. *See Transmit-Receive Application* at 24.

[11] As with grant of the original blanket AES authorization, the Commission can grant the instant application subject to the submission of a compliance report prior to the commencement of commercial service using the reflector antenna AES.

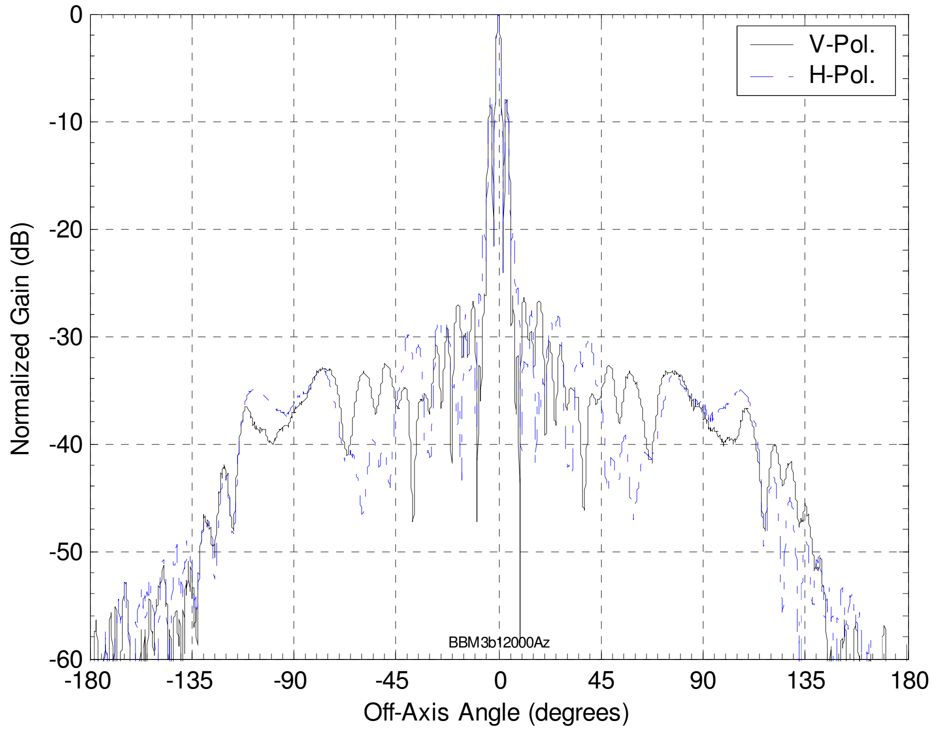

Figure 2: Azimuth Plane Receive Pattern, 12.0 GHz

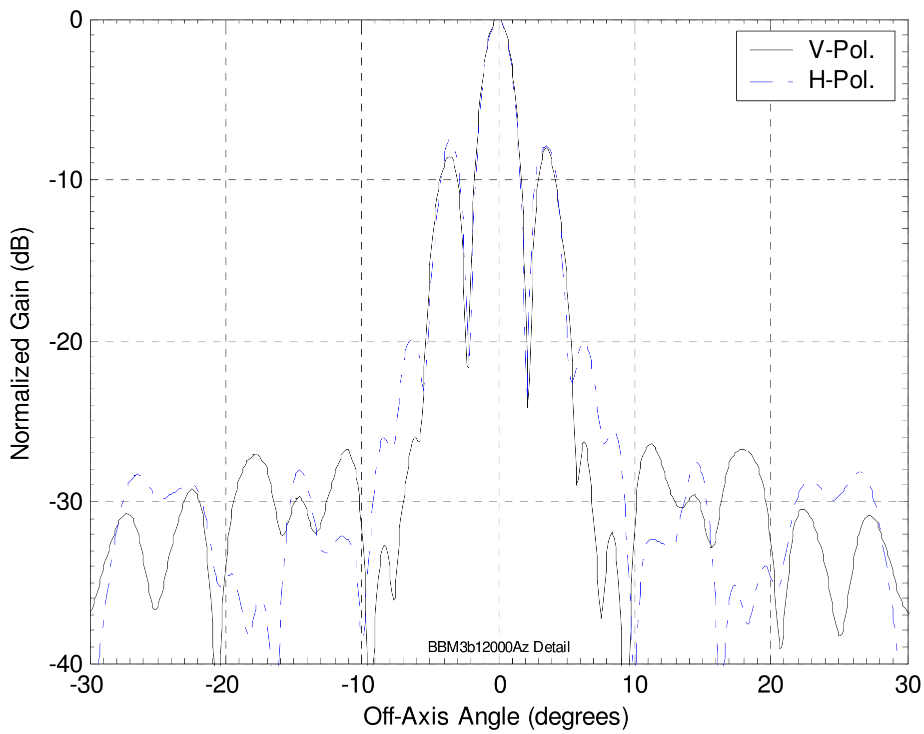

Figure 3: Azimuth Plane Receive Pattern, 12.0 GHz (Detail)

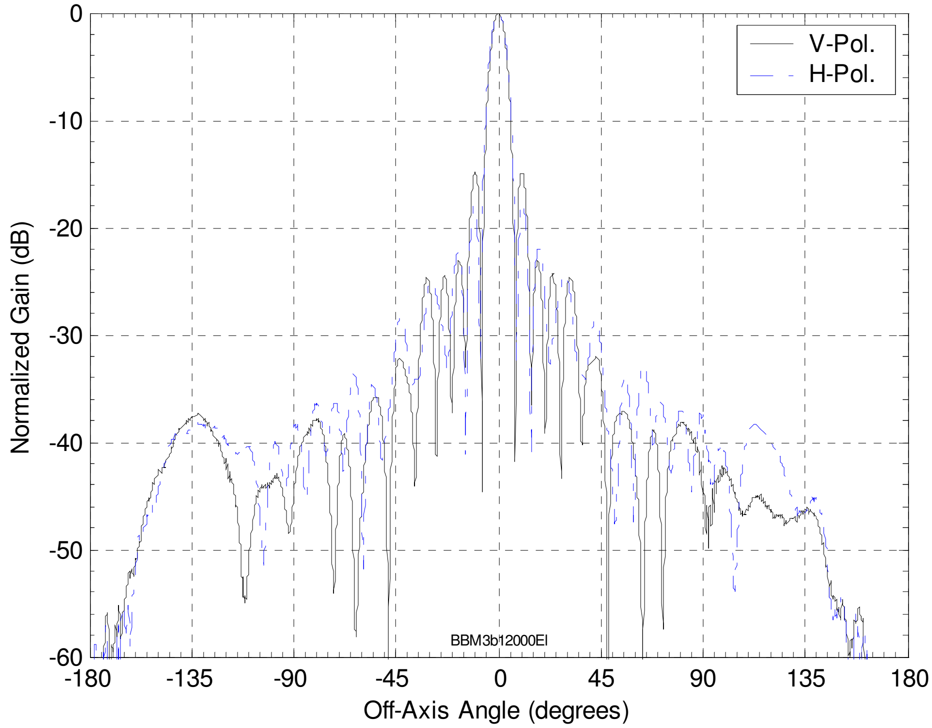

Figure 4: Elevation Plane Receive Pattern, 12.0 GHz

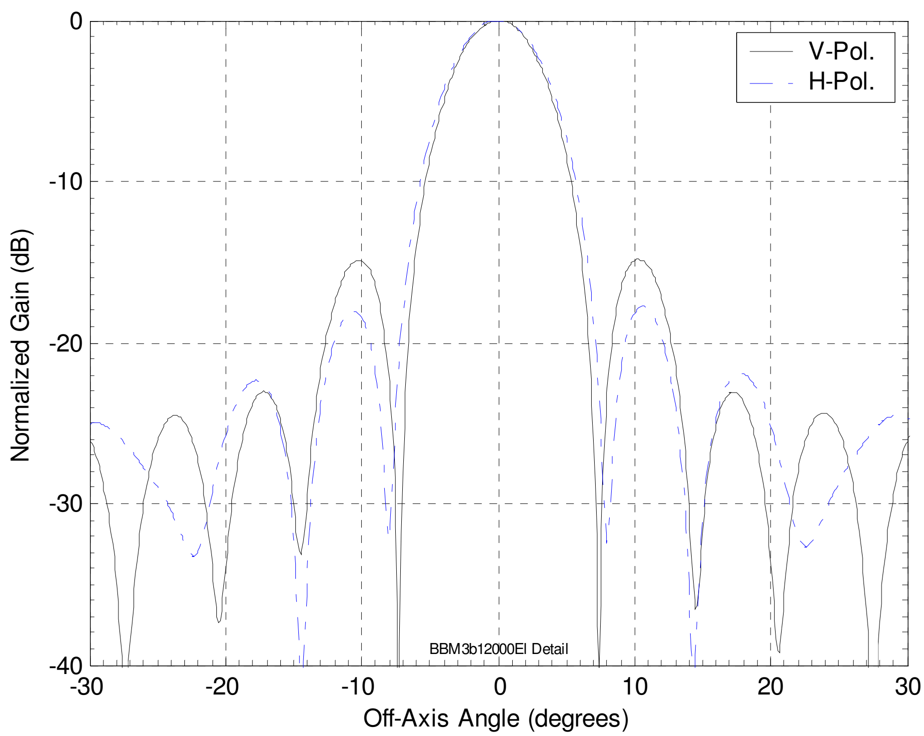

Figure 5: Elevation Plane Receive Pattern, 12.0 GHz (Detail)

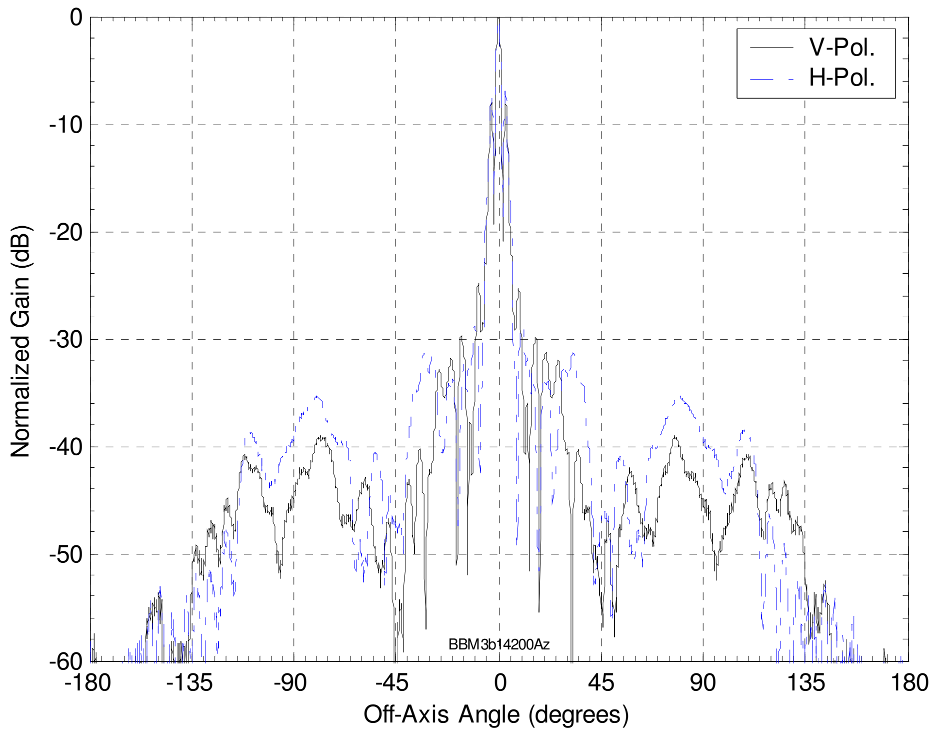

Figure 6: Azimuth Plane Transmit Pattern, 14.2 GHz

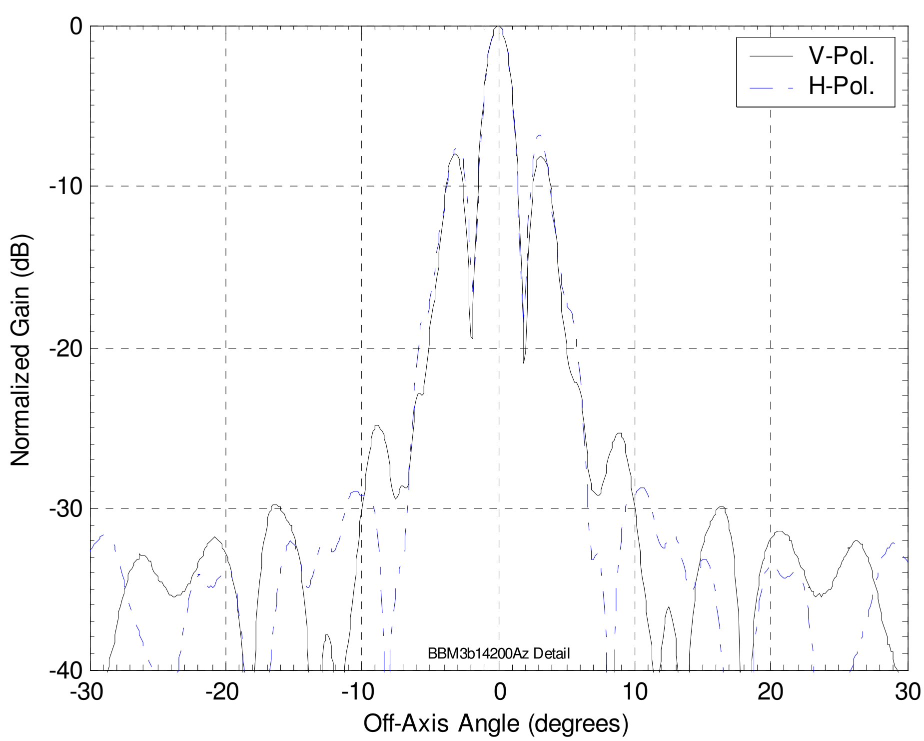

Figure 7: Azimuth Plane Transmit Pattern, 14.2 GHz (Detail)

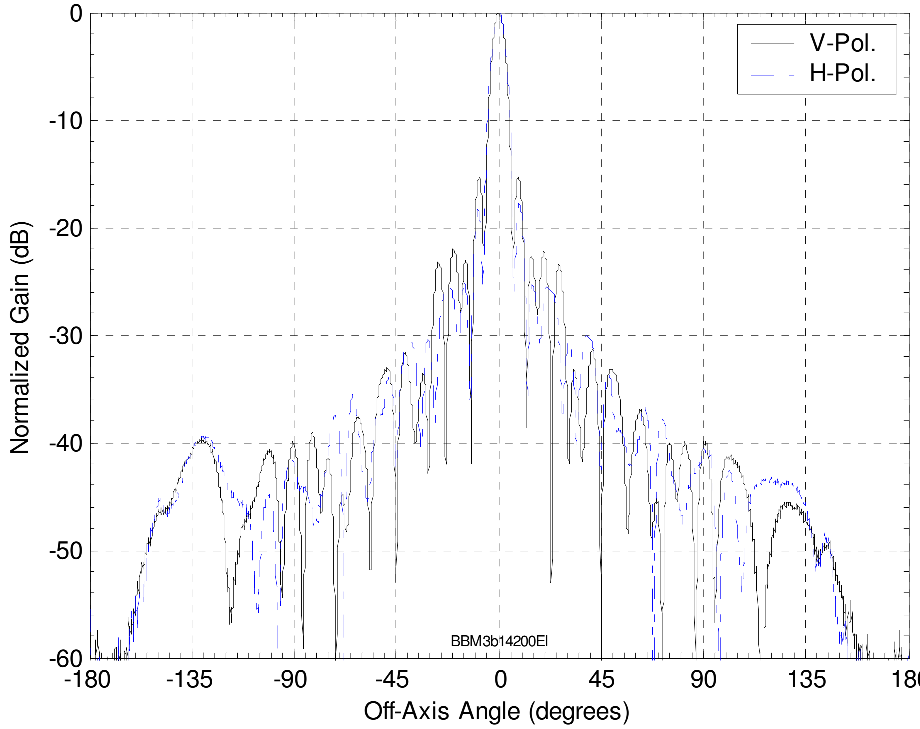

Figure 8: Elevation Plane Transmit Pattern, 14.2 GHz

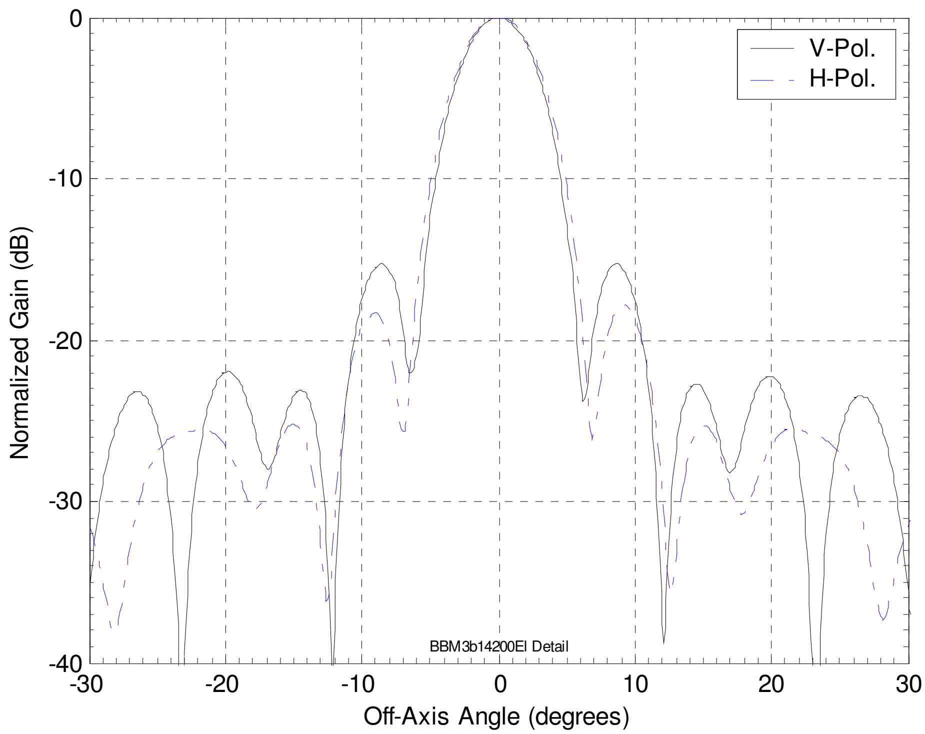

Figure 9: Elevation Plane Transmit Pattern, 14.2 GHz (Detail)

3.3 Reflector Antenna AES Typical Link Budgets

Typical link budgets are provided below for the forward and return links of the reflector antenna AES. A forward link budget for a nominal 5 Mbps data signal (spread to 32.4 MHz) is shown in Figure 10. 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 adjacent satellites on either side with 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 reflector antenna AES has sufficient margin to close the link at the requisite design availability.

Forward Downlink Budget Summary

ITU Rain Region		E
Elevation Angle	deg	45.0
Transponder Frequency	GHz	12.0
Spread Bandwidth	MHz	32.4
Transponder EIRP	dB W	48.0
Clear Sky Path Loss	dB	205.5
Atmospheric Attenuation	dB	0.56
Polarization Tracking Loss	dB	0.32
Pointing Loss	dB	0.50
Aircraft Receive Antenna Gain	dB	31.6
Receive Power at Aircraft	dB W	-127.3
Information Rate	Mbps dB Hz	5.00 67.0
Eb	dB W/Hz	-194.4
Aircraft Receive Noise Temperature	K dB K	149 21.7
No	dB W/Hz	-206.9
Co-Polarization Interference	dB W	-133.0
Cross-Polarization Interference	dB W	-141.0
Total Receive Interference Power	dB W	-132.4
Io Adjacent Satellite	dB W/Hz	-207.5
No + Io	dB	-204.2
Eb/(No+Io) Downlink	dB	9.8
Forward Link End-to-End Summary		
Eb/No Uplink	dB	34.0
Eb/(No+Io) Downlink	dB	9.8
Eb/(No+Io) End-to-End	dB	9.8
Eb/No Required	dB	3.3
Margin	dB	6.5

Figure 10: Typical Reflector Antenna AES Forward Link Budget

A return link budget for a nominal 1024 kbps data signal (spread to 32.4 MHz) is shown in Figure 11. The adjacent satellite uplink interference calculation assumes the presence of interfering uplinks from adjacent satellites on either side at 2° spacing between orbital locations. Each interfering uplink is assumed to have co-polarization and cross-polarization off-axis E.I.R.P. characteristics consistent with the maximum permitted for routine processing limits for earth stations, which is consistent with the prior coordination for the transponders used by the Boeing system. The link budget shows that the reflector antenna AES has sufficient E.I.R.P. to close the link at the requisite design availability.

Return Uplink Budget Summary

ITU Rain Region		E
Elevation Angle	deg	45.0
Transponder Frequency	GHz	14.2
Spread Bandwidth	MHz	32.4
Available Transmit EIRP	dB W	46.7
Output Back Off	dB	2.1
Transmit EIRP	dBW	44.6
Path Loss	dB	207.0
Atmospheric Attenuation	dB	0.6
Polarization Tracking Loss	dB	0.3
Pointing Loss	dB	0.50
Satellite Gain	dB	30.0
Receive Power	dB W	-133.7
Data Rate	kpbs	1024
	dB Hz	60.1
Eb	dB W/Hz	-193.8
Receive System Temperature	K	794.3
	dB K	29.0
No	dB W/Hz	-199.6
Io Adjacent Satellite Uplink	dB W/Hz	-203.4
No + Io	dB W/Hz	-198.1
Eb/(No+Io)	dB	4.3

Return Link End-to-End Summary

Eb/(No + Io) Uplink	dB	4.3
Eb/No Downlink	dB	21.9
Eb/(No+Io) End-to-End	dB	4.2
Eb/No Required	dB	4.2
Margin (Output Back Off)	dB	2.1

Figure 11: Typical Reflector Antenna Return Link Budget

3.4 Compliance with Design Guidelines

Boeing confirms that the Connexion system, using both phased array and reflector antenna AESs will continue to comply with the specific design guidelines set forth in ¶19(h)(1)-(5) of the *Transmit-Receive Order*. Section 3.4.1 covers control and monitoring functions (¶19(h)(3)-(4)). Section 3.4.2 covers the control of aggregate off-axis E.I.R.P (¶19(h)(1)). Section 3.4.3 covers factors that affect off-axis E.I.R.P. (¶19(h)(5.1)-(5.3)) including mis-pointing of the reflector antenna AES, variations in the reflector antenna pattern, and variations in reflector antenna AES transmit E.I.R.P.. The resistance of the reflector antenna to being "pulled off" to adjacent satellites (¶19(h)(2)) has already been addressed in Section 3.1.

3.4.1 Control and Monitoring Functions

The addition of reflector antenna AESs to the Connexion system does not affect the control and monitoring functions that are included in the system to ensure that AES transmissions always remain under positive control, and to identify and shut down any malfunctioning AES, as described in the *Transmit-Receive Application*[12] and license compliance report.[13] The Boeing system will continue to be controlled by a network control and monitoring facility ("NCMC") (¶19(h)(3)), which is referred to as the network operations center ("NOC") in the Connexion system. The reflector antenna AESs also will be able to receive "enable transmit" and "disable transmit" commands (¶19(h)(4.1)), cease transmissions after receiving any "parameter change" command which may cause harmful interference to other satellite systems during the change (¶19(h)(4.1)), and continue to be monitored by the NOC and on-board self-monitor (¶19(h)(4.2)).

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[12] *See Transmit-Receive Application*, Technical Supplement at 5, 8-13, and 34-40.

[13] *See* Compliance Report at 1-3.

3.4.2 Control of Off-Axis E.I.R.P.

The addition of reflector antenna AESs to the Connexion system does not fundamentally affect the algorithm employed by the NOC to control the aggregate off-axis E.I.R.P. of the system to less than or equal to that of a routinely processed VSAT terminals (¶19(h)(5)),[14] which is described in the *Transmit-Receive Application*[15] and license compliance report.[16] All AESs operating in the network continue to report their position (latitude, longitude), attitude (heading, pitch, roll), and transmit E.I.R.P. to the NOC. The NOC then uses the reported data, antenna models for each antenna type, and the known tolerances in pointing, antenna pattern, and transmit E.I.R.P. for each antenna type, to compute an aggregate off-axis E.I.R.P. envelope for the AESs operating in the network. This envelope is then compared to the off-axis E.I.R.P. limits for routinely processed VSAT terminals. Based on how closely the envelope approaches the limits, the NOC issues commands to allow additional AESs into the network, change AES data rates/power levels, or remove AESs from the network. Other than adding the specific reflector antenna model and tolerances (discussed in Section 3.4.3), no changes are needed to this algorithm.

3.4.3 Factors Affecting Off-Axis E.I.R.P.

While the fundamental algorithm employed by the NOC to control the aggregate off-axis E.I.R.P. is unchanged for the reflector antenna AES, the specific reflector antenna model and

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[14] Loral Skynet, the operator of Telstar 6, has indicated to Boeing that it has coordinated Telstar 6 with the satellites adjacent to 93° W.L. for off-axis E.I.R.P. levels that are less than or equal to that of a routinely processed VSAT terminal. SES Americom, the operator of AMC-4, has also confirmed that it has coordinated AMC-4 with the satellites adjacent to 101° W.L. for similar off-axis E.I.R.P. levels.

[15] *See* Boeing *Transmit-Receive Application*, Technical Supplement at 34-38.

[16] *See* Compliance Report at 3-5.

tolerances used by the NOC to account for antenna mis-pointing (¶19(h)(5.1)), pattern variation (¶19(h)(5.2)), and E.I.R.P. variation (¶19(h)(5.2)) must be included in the algorithm.

Reflector Antenna Mis-Pointing – As previously discussed in Section 3.1, the reflector antenna AES is designed to achieve a pointing accuracy of 0.25º 1-sigma in the azimuth plane (which aligns roughly along the GSO from mid to high latitudes) and 0.6º 1-sigma in the elevation plane (which is roughly perpendicular to the GSO from mid to high latitudes) in the dynamic environment of a commercial aircraft. Note that the pointing accuracy of the reflector antenna AES in the azimuth plane is equivalent to the value used by the NOC to account for mis-pointing of the previously authorized phased array antenna AES, as described in the license compliance report.[17] The NOC will account for the actual projection of the reflector antenna pointing accuracy onto the GSO arc when computing the off-axis E.I.R.P. envelope for the reflector antenna.

Reflector Antenna Pattern Variation – The reflector antenna model used by the NOC will be substantially simplified because, unlike the phased array antenna, the reflector antenna pattern varies little with antenna pointing angles (elevation and azimuth). Reflector antennas are generally easier to predict and have less unit-to-unit variation than phased arrays. The reflector antenna model used by the NOC will be based on the as built performance of the reflector antenna, adjusted to account for unit-to-unit variation and radome effects, and projected along the GSO arc.

Reflector Antenna E.I.R.P. Variation – The transmit E.I.R.P. reported by reflector antenna AESs to the NOC will be more accurate than the E.I.R.P. reported by phased array antenna AESs because the input power to the reflector antenna is measured after output of the high power amplifier and because the reflector antenna gain is very predictable. At maximum

[17] *See* Compliance Report at 7.

power, the reported E.I.R.P. uncertainty of the reflector antenna AES will be only 0.5 dB (1-sigma). Note that the reported E.I.R.P. uncertainty of the reflector antenna is substantially lower than for the previously authorized phased array antenna, as described in the license compliance report.[18] The NOC will account for this error when computing the off-axis E.I.R.P. envelope for the reflector antenna AES.

Boeing will verify each of these parameters through testing and use the measured values in the NOC when accounting for the variation in off-axis E.I.R.P. caused by these factors.

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[18] *See* Compliance Report at 11-12.