THE BOEING COMPANY

Application of The Boeing Company for Authority
to Operate Up to 100
Earth Stations Aboard Aircraft ("ESAA")

Technical Appendix

September 22, 2014

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1 Boeing Phased Array Antenna

The Boeing Phased Array Antenna ("PAA") sub system contains a separate receive and transmit antenna. Both the receive and transmit antenna are fixed to the top of the aircraft fuselage and use electronic beam steering to track the desired satellite through aircraft flight maneuvers and over a large geographic range. The receive antenna employs a closed loop pointing algorithm to track the desired satellite with the transmit antennas pointing being continuously slaved to the resulting pointing vector. Figure 1 shows a representative installation of the PAA antennae. Table 1 summarizes important receive and transmit antennae characteristics.

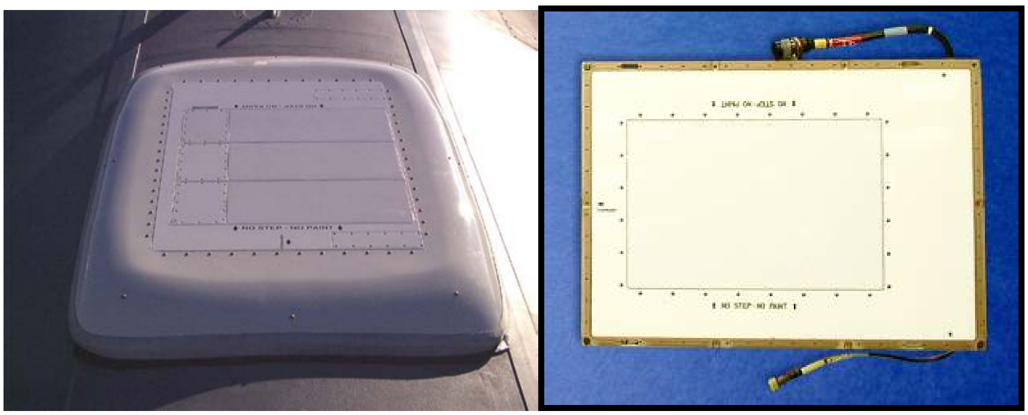


Figure 1. Representative PAA Receive and Transmit Antennae

Specification	**Antenna Data**
Aperture Dimensions	
Receive	17"x24" (uniform illumination)
Transmit	15" circular (uniform illumination)
Transmit Band	14.0-14.5 GHz
Receive Band	11.45-12.75 GHz
Frequency Tolerance	+/-10 kHz
EIRP	51.2 dBW @ 0^{o} Scan
G/T	12.5 dB/K @ 0^{o} Scan
Transmit Gain	34.9 dBi at 14.2 GHz
Receive Gain	36.7 dBi at 12.0 GHz
Polarization	Linear

Table 1. Antenna Characteristics Summary

One attribute of a phased array antenna is its level of scan loss. Scan loss refers to the decrease in gain that occurs as a phased array antenna operates at an increased scan angle, and the increase in beam width that results as the beam is scanned from zenith. The antenna gain falls off nearly as the cosine of the scan angle. The design specifications for the Boeing system allow for scan angles of up to 75 degrees. As a minimum, the antennae can acquire and maintain track within a cone extending to a 75 degree scan from vertical over a full 360 degrees of azimuth.

There are no ‘keyholes’ or areas of blockage within this cone. The antennae have been operational for airborne mobile operations without incident for more than 10 years.

1.1 Antenna Control and Pointing

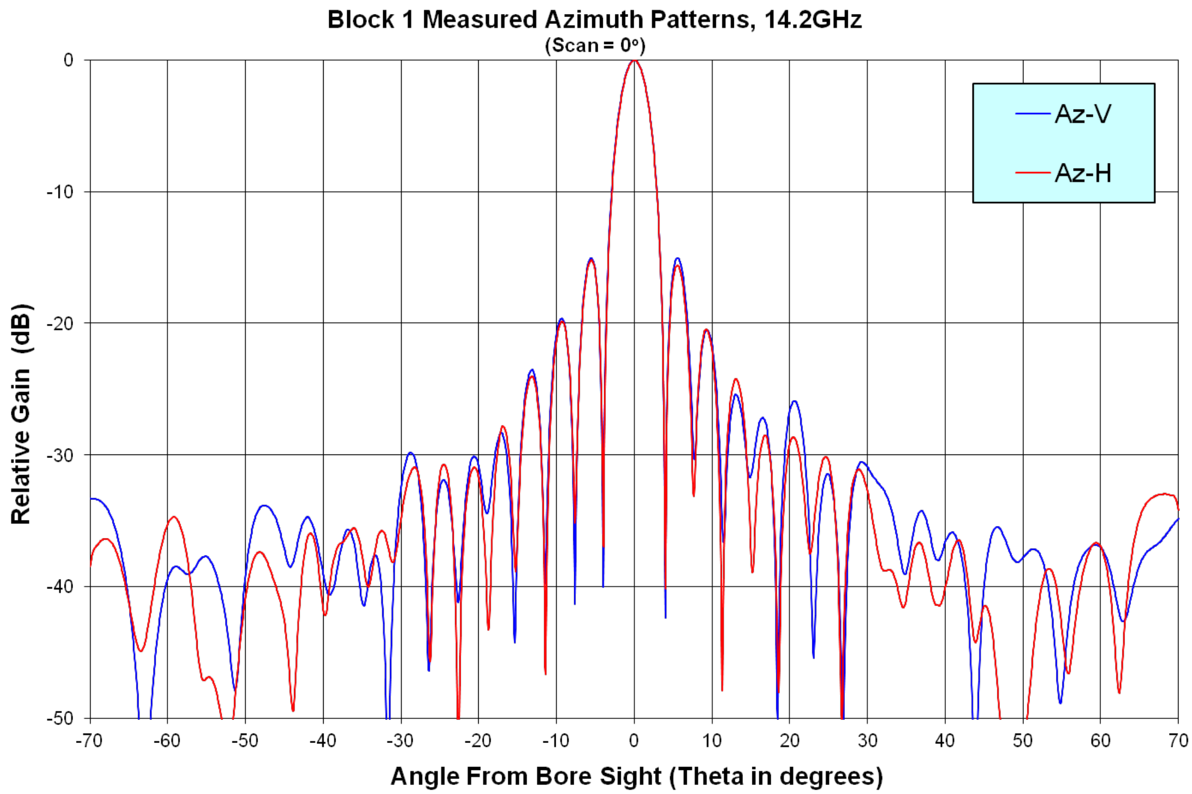
Accurate pointing of the receive and transmit antennas is achieved by closed loop pointing of the receive antenna towards a desired satellite and slaving of the transmit beam to the receive beam calculated direction. Initial acquisition of the satellite is accomplished through the use of the aircraft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

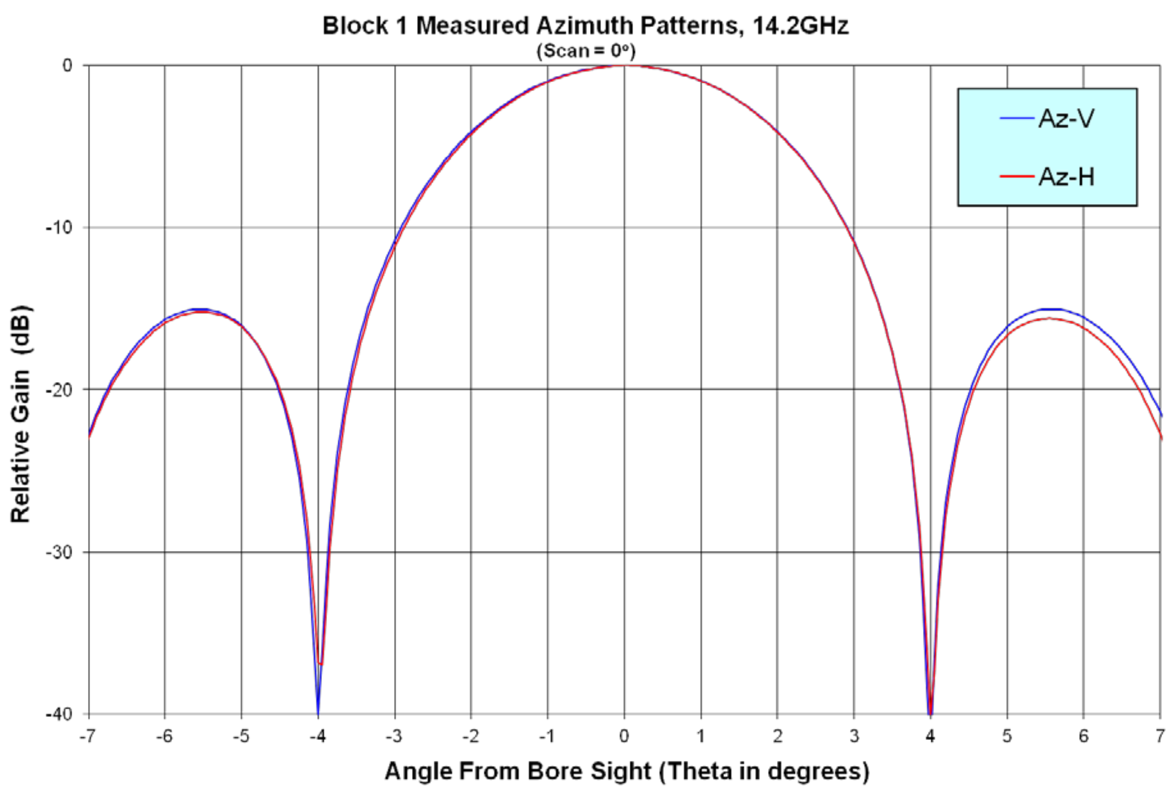
The receive antenna performs a conical scan pointing algorithm sequential lobing at four points about the pointing vector between the aircraft and the satellite and, using the measured receive signal strengths for each of these four lobing points, updates the pointing vector. The receive antenna performs this operation about 50 times per second and can accurately point to the satellite during extreme aircraft movements. The transmit antenna pointing vector is updated at a rate of about 50 times per second based on the pointing vector calculated by the receive antenna. Since both the receive and transmit antennas are electronically steered, the antennas are able to change their pointing vectors to any visible location in the sky at each update cycle (50 times a second). Using this algorithm, the only tracking error that the PAA transmit antenna will exhibit is the one inherent in the 20 ms update rate. At every pointing update the antenna will be pointing at the satellite location. The PAA pointing error will be less than 0.1 degrees.

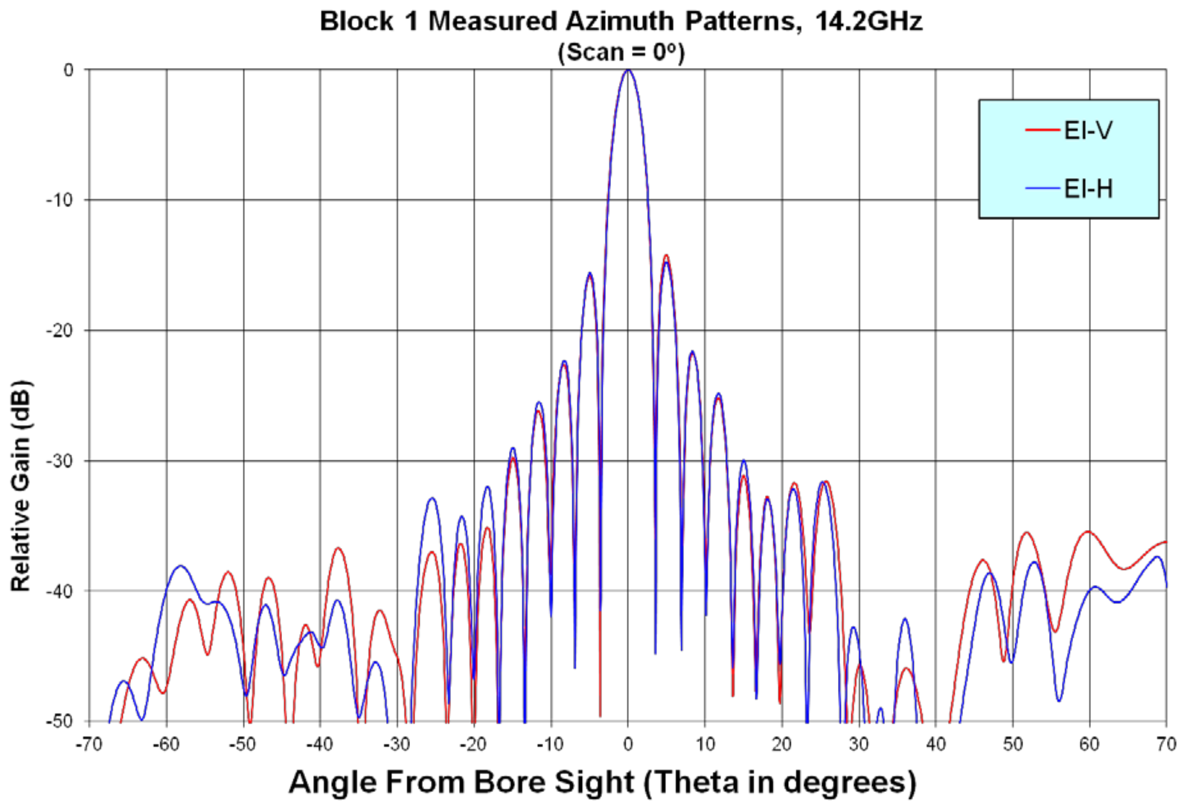
Receive antenna polarization tracking is performed using the receive signal strengths similar to the closed loop pointing algorithm, but the cycle rate is reduced to about 25 times per second to avoid coupling with the pointing algorithm. For subsequent passes through the algorithm, the polarization is dithered in opposite directions and the differences in the signal strength measurements are used to calculate best polarization angle. The transmit antenna polarization is set by an open loop using both the airplane location information as well as the antenna transmit vector information and is updated at the same rate as the spatial pointing vector.

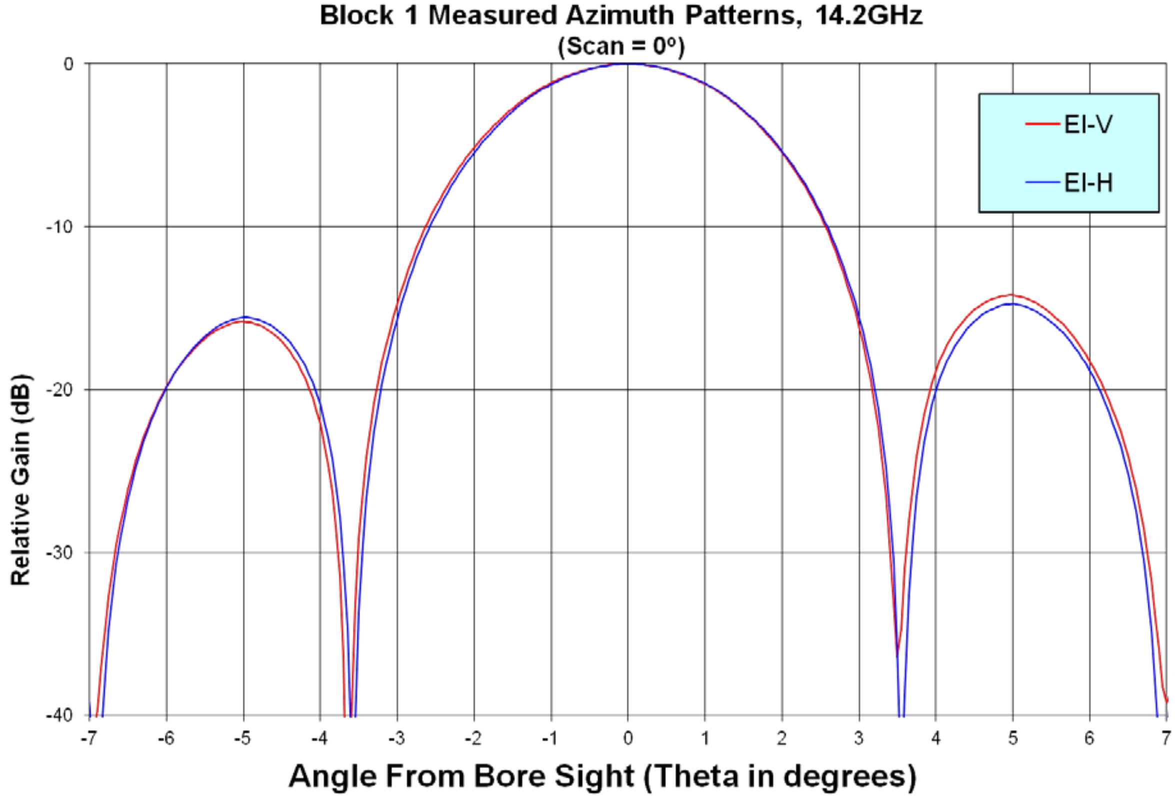
1.2 Transmit Antenna Patterns

Pursuant to Section 25.132(b)(1-2), Boeing provides the following antenna gain patterns for the Boeing PAA. Both azimuth (Az) and elevation (El) patterns are provided for vertical (V) and horizontal (H) polarization at 14.2 GHz.


Block 1 Measured Azimuth Patterns, 14.2GHz
(Scan = 0°)
Az-V
Az-H
Relative Gain (dB)
Angle From Bore Sight (Theta in degrees)
0
-10
-20
-30
-40
-50
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70


Block 1 Measured Azimuth Patterns, 14.2GHz
(Scan = 0°)
Az-V
Az-H
Relative Gain (dB)
Angle From Bore Sight (Theta in degrees)
0
-10
-20
-30
-40
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7


Block 1 Measured Azimuth Patterns, 14.2GHz
(Scan = 0º)
El-V
El-H
Relative Gain (dB)
0
-10
-20
-30
-40
-50
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
Angle From Bore Sight (Theta in degrees)


Block 1 Measured Azimuth Patterns, 14.2GHz
(Scan = 0º)
El-V
El-H
Relative Gain (dB)
0
-10
-20
-30
-40
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
Angle From Bore Sight (Theta in degrees)

2 MELCO Reflector Terminal

The second of the terminals used with the BBSN is the MELCO Reflector Terminal developed by Mitsubishi Electronics Company ("MELCO") for Boeing. The reflector terminal transmits and receives 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 is mounted on the top of the aircraft body and enclosed in a radome. Associated support electronics will be installed in the aircraft fuselage. Table 2 below provides the specifications for the reflector terminal, and Figure 2 provides a picture of the antenna.

Specification	**Antenna Data**
Aperture Dimensions	65.0 x 19.6 cm elliptical
Transmit Band	14.0-14.5 GHz
Receive Band	11.2-12.75 GHz
Frequency Tolerance	+/-10 kHz
EIRP	46.7 dBW
G/T	10.5 dB/K
Transmit Gain	33.1 dBi at 14.2 GHz
Receive Gain	31.6 dBi at 12.0 GHz
Polarization	Linear

Table 2. Reflector Terminal Specifications

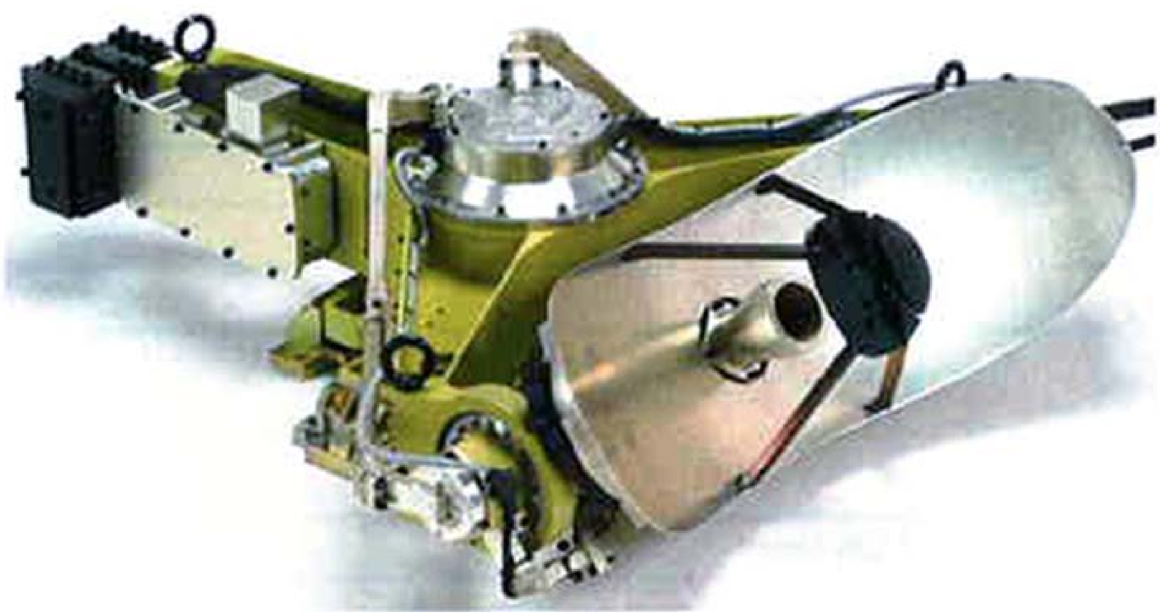


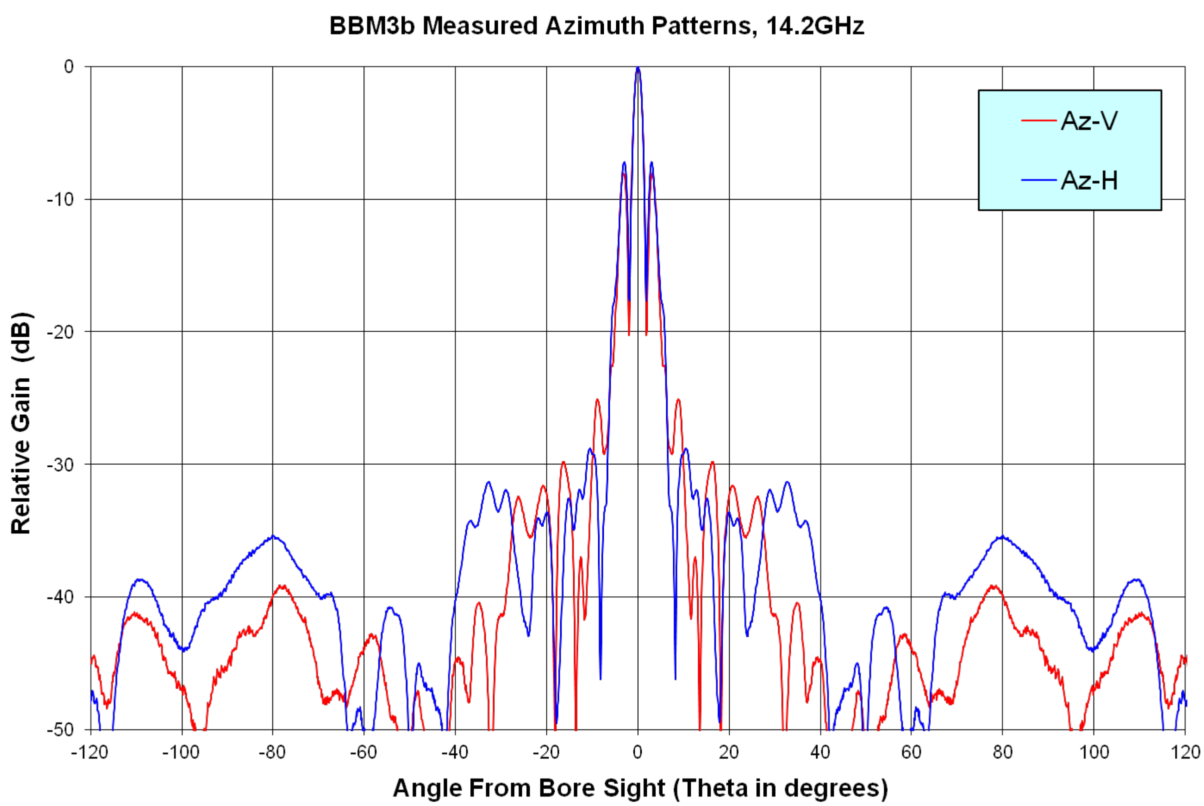
Figure 2. Reflector Terminal

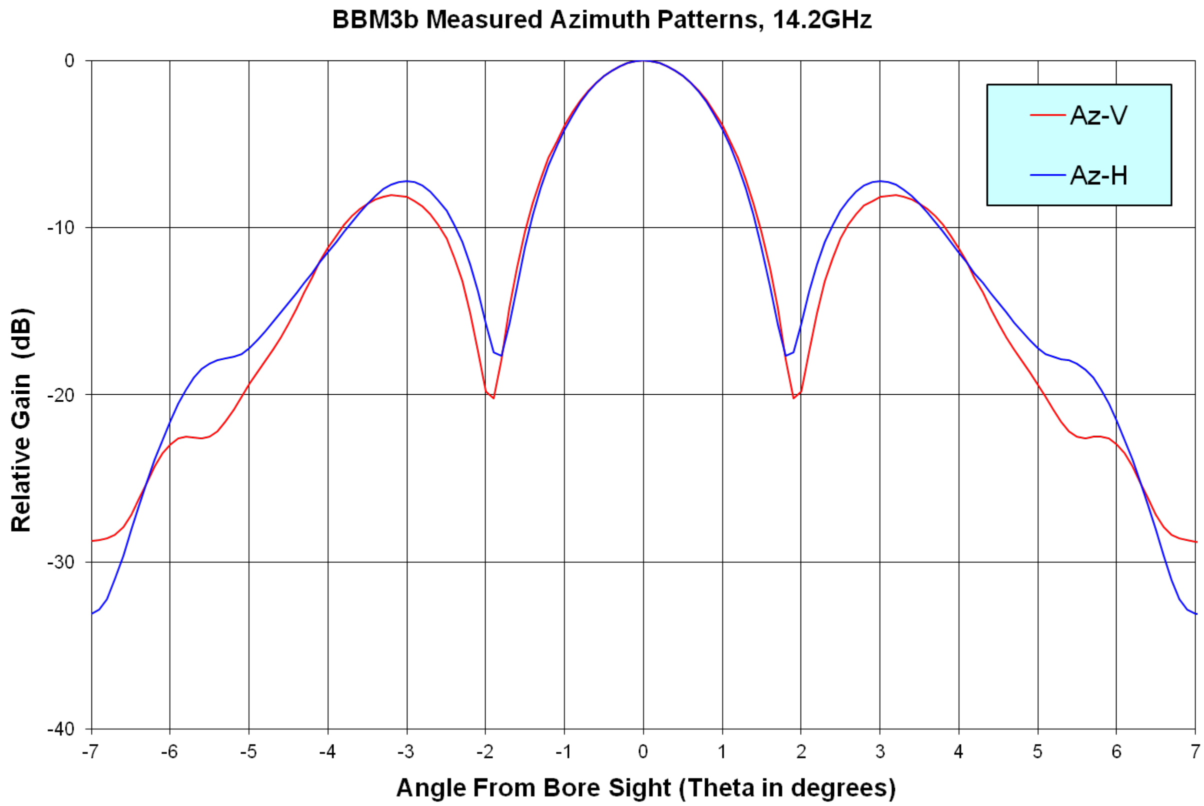
2.1 Antenna Control and Pointing

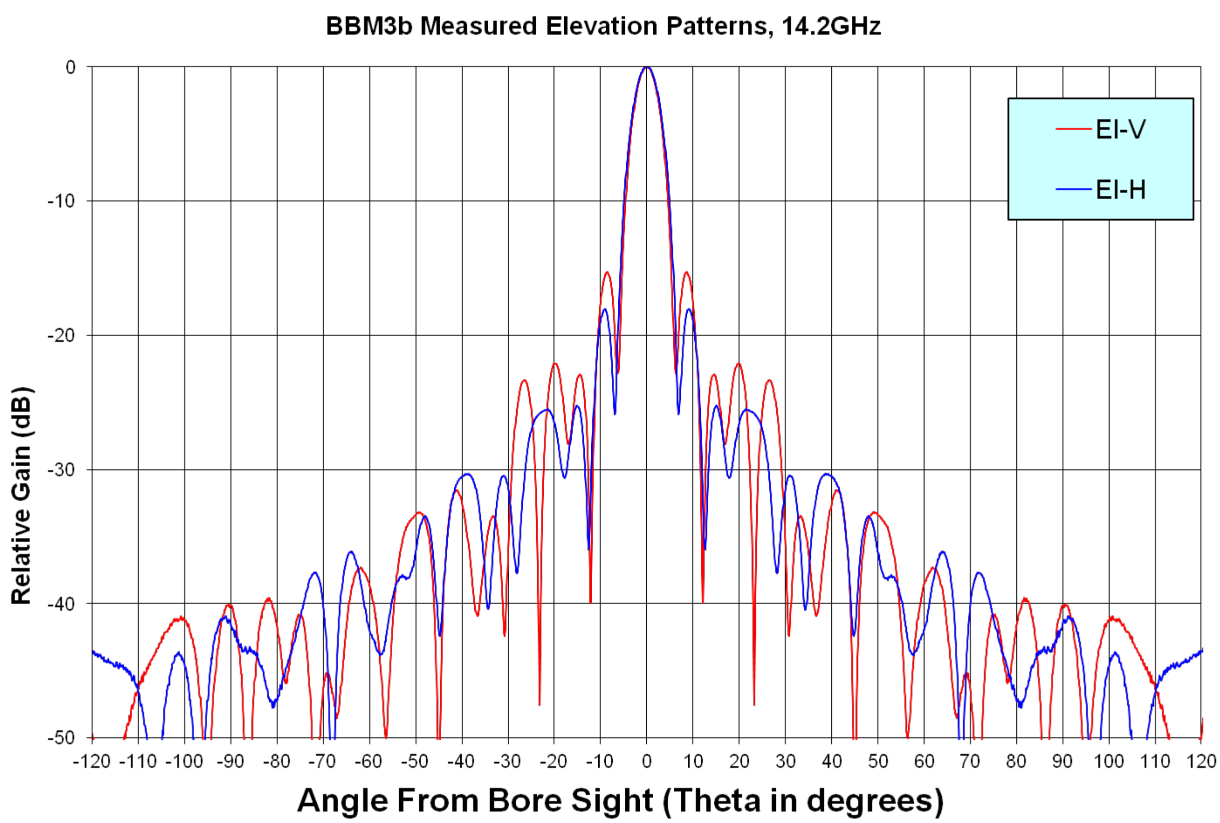
Pointing for the MELCO Reflector Terminal is accomplished via mechanical steering of the antenna and uses the aircraft attitude data (i.e. yaw, roll, pitch, yaw rate, roll rate, pitch rate, and heading vector), together with location of the terminal (latitude, longitude, and altitude) to calculate the command vectors. This data, available from the ARINC 429 bus, is used in conjunction with the satellite coordinates to yield continuously updated steering commands for the antenna elevation, azimuth, and polarization. A local inertial sensor package placed on the antenna base plate itself provides high rate antenna attitude sensing, which compensates for possible aircraft inertial navigation system ("INS") errors caused by airframe deformation and data latency. The MELCO Reflector Terminal is capable of reliably maintaining a 0.2 degrees pointing accuracy through all anticipated flight maneuvers. Pointing error will be monitored and emissions will be inhibited if the pointing error ever exceeds 0.5 degrees.

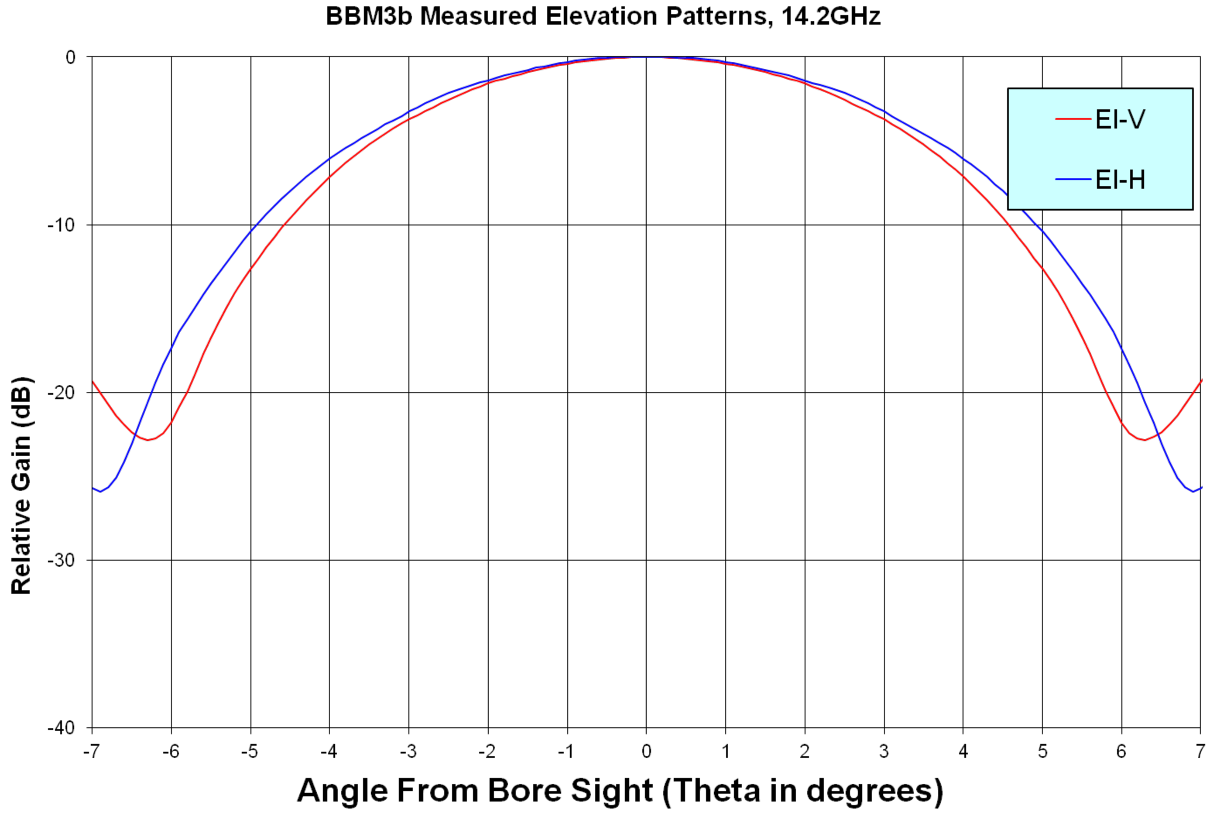
2.2 Antenna Gain Patterns

Pursuant to §25.132(b)(1-2), Boeing provides the following antenna gain patterns for the MELCO Reflector Terminal, which is labeled below by Mitsubishi as model BBM3b. Both azimuth (Az) and elevation (El) patterns are provided for vertical (V) and horizontal (H) polarization at 14.2 GHz.




BBM3b Measured Azimuth Patterns, 14.2GHz
Az-V
Az-H
Relative Gain (dB)
Angle From Bore Sight (Theta in degrees)
0
-10
-20
-30
-40
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7


BBM3b Measured Elevation Patterns, 14.2GHz
El-V
El-H
Relative Gain (dB)
Angle From Bore Sight (Theta in degrees)
0
-10
-20
-30
-40
-50
-120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120



3 TECOM KuStream 1500

The KuStream 1500 terminal ("KuStream 1500"), manufactured by TECOM, is an increased EIRP version of the KuStream terminal that has been previously authorized by the Commission for both experimental and commercial operations. For example, the TECOM terminal was authorized for aeronautical experimental operations by Row 44, Inc. in 2009 (File No. 0236-EX-PL-2009, Call Sign WF2XBY), and for commercial operations in 2010 (File No. SES-MOD-20091021-01342, Call Sign E080100). The KuStream 1500 terminal transmits and receives using a single horn array aperture 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 horn array aperture is mounted on the top of the aircraft body and enclosed in a radome. Associated support electronics will be installed in the aircraft fuselage. Table 3 below provides the specifications for the KuStream 1500 terminal, and Figure 3 provides a picture of the antenna

Specification	Antenna Data
Aperture Dimensions	65.0 x 17.5 cm rectangular
Transmit Band	14.0-14.5 GHz
Receive Band	11.45-12.75 GHz
Frequency Tolerance	+/-10 kHz
G/T	11.9 dB/K
Transmit Gain	32.5 dBi

Receive Gain	31.5 dBi
EIRP	44.8 dBW
Pointing Error	< 0.2 degrees

Table 3. KuStream 1500 Specifications

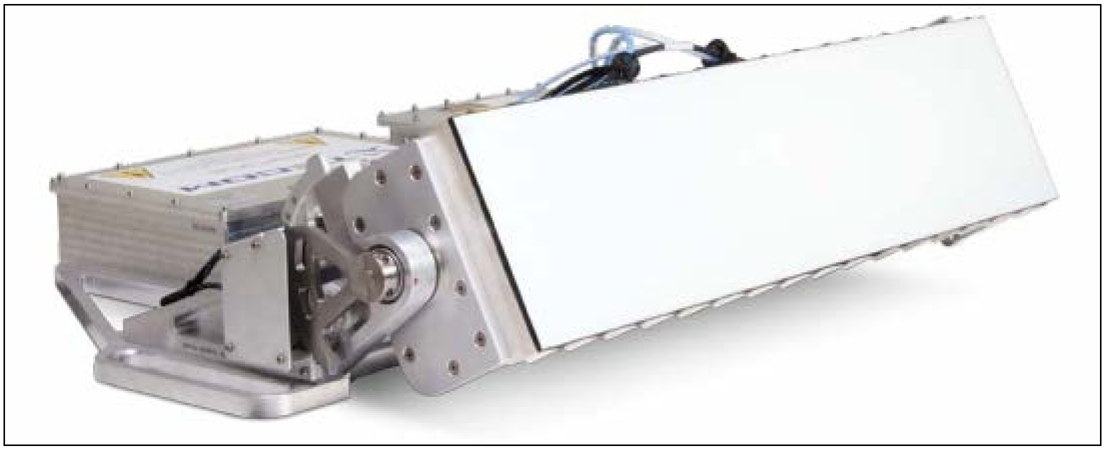


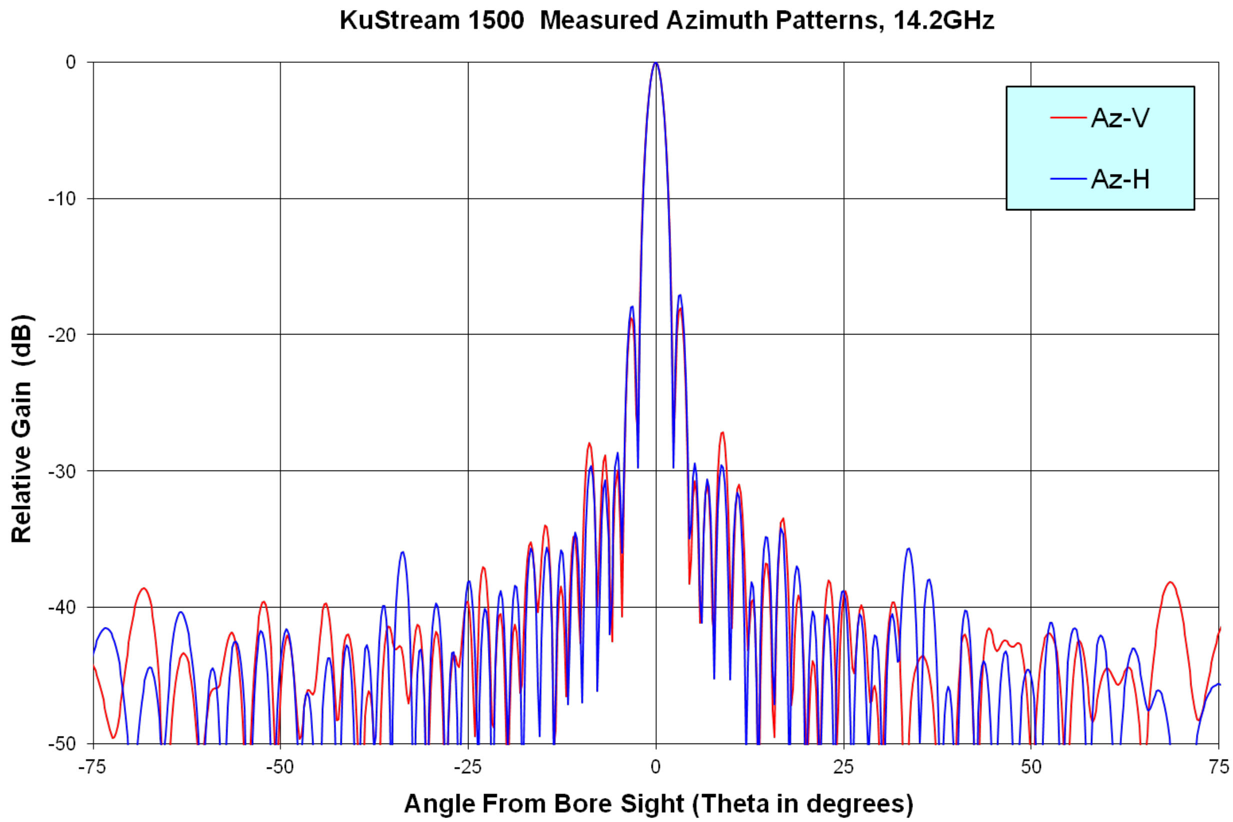
Figure 3. TECOM KuStream 1500

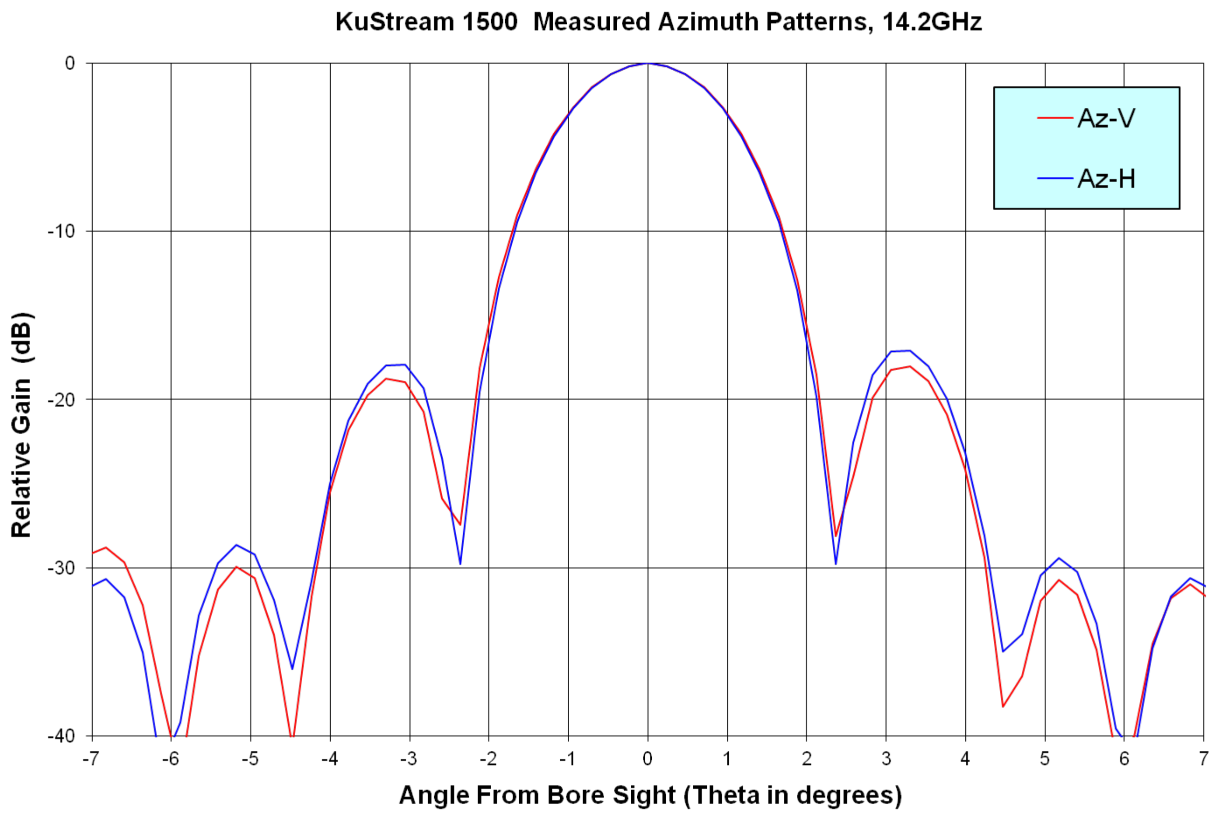
3.1 Antenna Control and Pointing

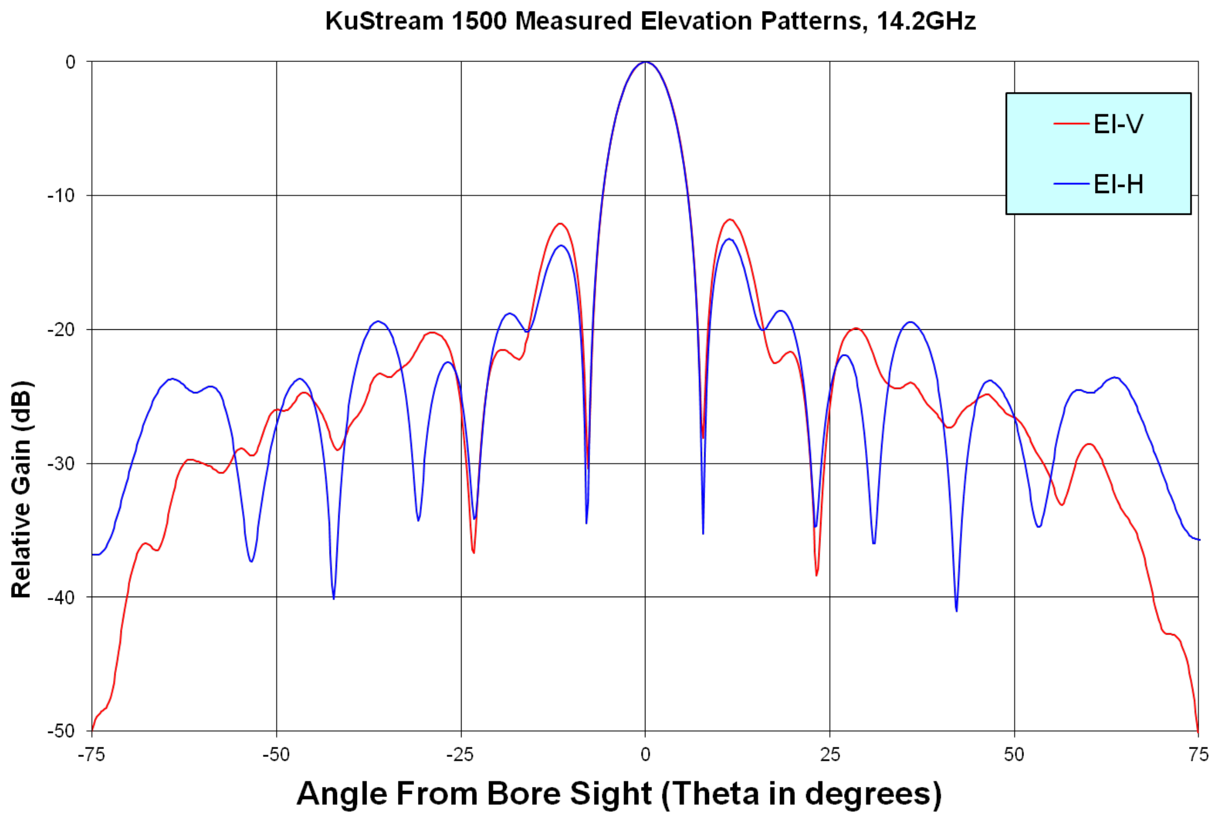
The KuStream 1500 antenna employs mechanical steering of the aperture and uses the aircraft attitude data (i.e. yaw, roll, pitch, yaw rate, roll rate, pitch rate, and heading vector), together with location of the terminal (latitude, longitude, and altitude) to calculate the command vectors. The attitude and position data is provided to the antenna by a dedicated inertial reference unit (IRU) and is used in conjunction with the satellite coordinates to yield continuously updated steering commands for the antenna elevation, azimuth, and polarization. Using the dedicated low latency IRU that is located in close proximity to the antenna allows for a high rate position and attitude sensing and eliminates errors caused by airframe deformation and data latency. The KuStream 1500 is capable of reliably maintaining 0.2 degree pointing accuracy through all anticipated flight maneuvers. In the event that pointing offset exceeds 0.5 degree, the terminal will automatically mute transmissions within 100 milliseconds and delay resumption of transmissions until pointing accuracy is within 0.2 degrees.

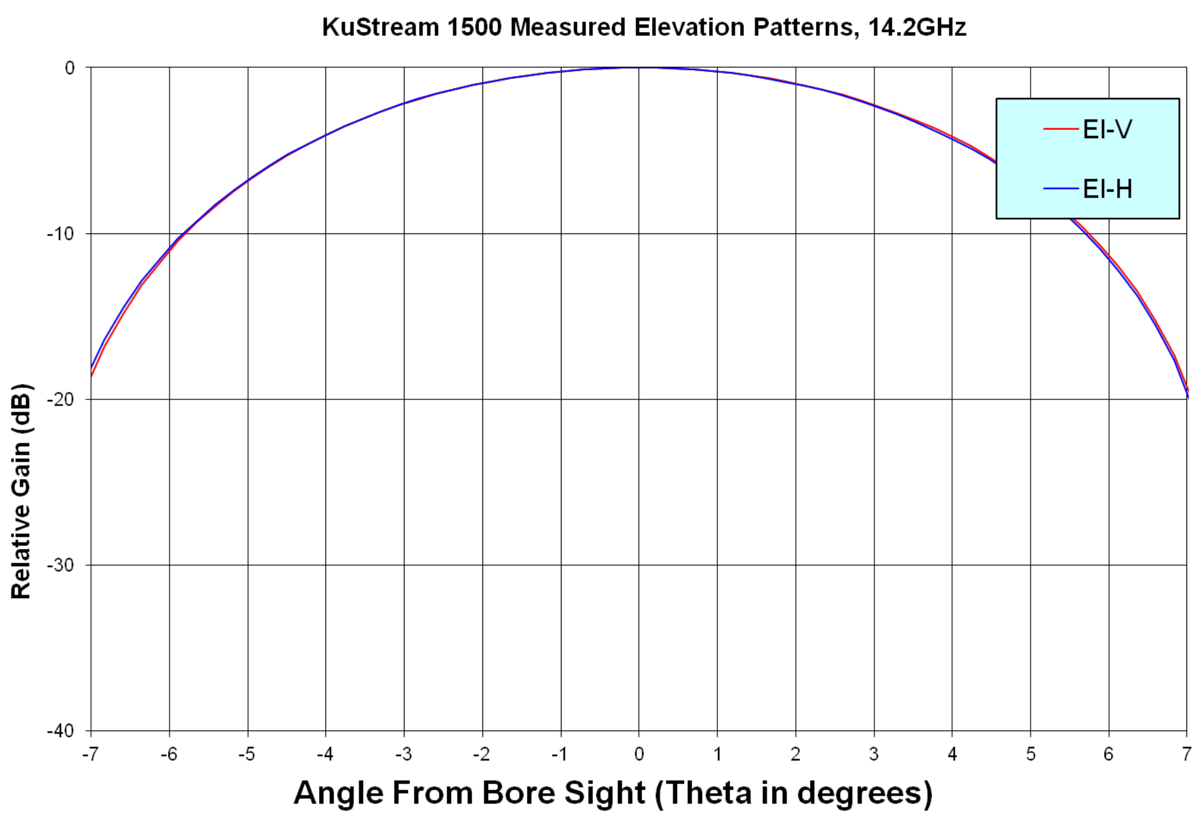
3.2 Antenna Gain Patterns

Pursuant to §25.132(b)(1-2), Boeing provides the following antenna gain patterns for the KuStream 1500 antenna. Both azimuth (Az) and elevation (El) patterns are provided for vertical (V) and horizontal (H) polarization at 14.2 GHz.


KuStream 1500 Measured Azimuth Patterns, 14.2GHz
Relative Gain (dB)
0
-10
-20
-30
-40
-50
-75
-50
-25
0
25
50
75
Angle From Bore Sight (Theta in degrees)
Az-V
Az-H


KuStream 1500 Measured Azimuth Patterns, 14.2GHz
Relative Gain (dB)
0
-10
-20
-30
-40
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
Angle From Bore Sight (Theta in degrees)
Az-V
Az-H


KuStream 1500 Measured Elevation Patterns, 14.2GHz
El-V
El-H
Relative Gain (dB)
0
-10
-20
-30
-40
-50
-75
-50
-25
0
25
50
75
Angle From Bore Sight (Theta in degrees)


KuStream 1500 Measured Elevation Patterns, 14.2GHz
El-V
El-H
Relative Gain (dB)
0
-10
-20
-30
-40
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
Angle From Bore Sight (Theta in degrees)

ATTACHMENT 1

Radiation Hazard Studies

This report presents an analysis of the non-ionizing radiation levels for a Boeing Phased Array antenna system.

The calculations used in this analysis were derived from and comply with the procedures outlined in the Federal Communications Commission, Office of Engineering and Technology, Bulletin Number 65, which establishes guidelines for human exposure to Radio Frequency Electromagnetic Fields. Bulletin 65 defines exposure levels in two separate categories, the General Population/Uncontrolled Areas limits, and the Occupational/Controlled Area limits. The Maximum Permissible Exposure (MPE) limit of the General Population/ Uncontrolled Area is defined in Table (1), and represents a maximum exposure limit averaged over a 30 minute period. The MPE limit of the Occupational/ Controlled Area is defined in Table (2), and represents a maximum exposure limit averaged over a 6 minute period. The purpose of this report is to provide an analysis of the aircraft station power flux densities, and to compare those levels to the specified MPE limits.

This report provides predicted density levels in the near field, far field, transition region, and main reflector surface area.

MPE Limits for General Population/Uncontrolled Area

Frequency Range (MHz)	*Power Density (mW/cm^2)*
1500 – 100,000	1.0

Table 1

MPE Limits for Occupational/Controlled Area

Frequency Range (MHz)	*Power Density (mW/cm^2)*
1500 – 100,000	5.0

Table 2

Table 3 contains formulas, equations and parameters that were used in determining the Power Flux Density levels for the Boeing Phased Array:

Data Type	Data Symbol	Data Formula	Data Value	Unit of Measure
Power Input	P	Input	42.7	W
Antenna Size	D	Input	0.381	m
Antenna Area	A	$A = \frac{\pi D^2}{4}$	0.1140	m^2
Subreflector Size	Sub	Input	N/A	cm
Subreflector Area	A_{sub}	$A_{sub} = \frac{\pi D_{Sub}{}^2}{4}$	N/A	cm^2
Gain dBi	G_{dbi}	Input	34.9	dBi
Gain Factor	G	$G = 10^{GdBi/10}$	3090.3	Gain Factor
Frequency	f	Input	14250	MHz
Wavelength	λ	$299.79 / f$	0.021038	m
Aperture Efficiency	η	$\eta = \frac{G\lambda^2}{4\pi A}$	.95	n/a
Pi	π	Input	3.14159	Numeric
Speed of Light	C	Input	299,792,458	m/sec
Conversion W to mW	mW	mW = $W \times 1000$	n/a	n/a
Conversion M to cm	cm	cm = $m \times 100$	n/a	n/a
Conversion M^2 to cm^2	cm^2	$cm^2 = m^2 \times 10000$	n/a	n/a
Conversion W/M^2 to mW/cm^2	mW/cm^2	$mW/cm^2 = \frac{W}{10m^2}$	n/a	n/a

Table 3

1. Far Field Analysis

The distance to the far field can be calculated using the following formula:

$$R_{ff} = \frac{0.6D^2}{\lambda} = \text{4.14 Meters}$$

The power density in the far field can be calculated using the following formula. Note: this formula requires the use of power in milliwatts and far field distance in centimeters, or requires a post calculation conversion from W/M^2: **For the purposes of this report we calculated the range where the occupational**

hazard limit of 5mW/cm^2 would be reached, thus establishing a keep out range for occupational workers.

$$S_{ff} = \frac{PG}{4\pi R_{ff}^{\ 2}}$$ = 61.267 mW/cm^2 or at **5mW/cm^2 R = 14.5 m**

2. Near Field Analysis

The extent of the Near Field region can be calculated using the following formula:

$$R_{nf} = \frac{D^2}{4\lambda}$$ = 1.72 m

The power density of the near field can be calculated using the following formula. Note: this formula requires the use of power in milliwatts and diameter in centimeters, or requires a post calculation conversion from W/M^2:

$$S_{nf} = \frac{16\eta P}{\pi D^2}$$ = 143.024 mW/cm^2

3. Transition Region Analysis

The transition region extends from the end of the near field out to the beginning of the far field. The power density in the transition region decreases inversely with distance from the antenna, while power density in the far-field decreases inversely with the square of the distance. However the power density in the transition region will not exceed the density in the near field, and can be calculated for any point in the transition region (R), using the following formula.

$$S_t = \frac{S_{nf} R_{nf}}{R}$$

4. Main Reflector Surface Area Analysis

The maximum power density at the antenna surface area can be calculated using the following formula. Note: this formula requires the use of Power in milliwatts and Area in centimeters squared, or requires a post calculation conversion from W/M^2.

$$S_{surface} = \frac{4P}{A}$$ = 149.812 mW/cm^2

Tables 4 and 5 present a summary of the radiation hazard findings on the Boeing Phased Array terminal for both the General Population/Uncontrolled Area, as well as the Occupational/Controlled area environments.

MPE Limits for General Population/Uncontrolled Area

Area	Range Meters	Power Density (mW/cm^2)	Finding
Far Field	4.14	61.267 mW/cm^2	Potential Hazard
Near Field	1.72	143.024 mW/cm^2	Potential Hazard
Transition Region	1.72 – 4.14	143.024 mW/cm^2	Potential Hazard
Main Reflector Surface	N/A	149.812 mW/cm^2	Potential Hazard

Table 4

MPE Limits for Occupational/Controlled Area

Area	Range Meters	Power Density (mW/cm^2)	Finding
Far Field	4.14	61.267 mW/cm^2	Potential Hazard
Near Field	1.72	143.024 mW/cm^2	Potential Hazard
Transition Region	5.02 – 12.05	143.024 mW/cm^2	Potential Hazard
Main Reflector Surface	N/A	149.812 mW/cm^2	Potential Hazard

Table 5

5. Summary

This document presents the radiation hazard for the Boeing Broadband System Network incorporating the Boeing Phased Array antenna and the maximum EIRP of 51.2 dBW. The radiation hazard is divided into two cases; General Public and Occupational. The General Public risk is mitigated by the placement of the antenna on the top of the aircraft, which is not accessible to the general public. The Occupational risk will be controlled by turning the system off prior to performing any antenna maintenance, accessing the top of the aircraft near the antenna, or operating personnel lifts or other similar equipment in the vicinity of the antenna hazard zone defined in this report.

This report presents an analysis of the non-ionizing radiation levels for a MELCO antenna system.

The calculations used in this analysis were derived from and comply with the procedures outlined in the Federal Communications Commission, Office of Engineering and Technology, Bulletin Number 65, which establishes guidelines for human exposure to Radio Frequency Electromagnetic Fields. Bulletin 65 defines exposure levels in two separate categories, the General Population/Uncontrolled Areas limits, and the Occupational/Controlled Area limits. The Maximum Permissible Exposure (MPE) limit of the General Population/ Uncontrolled Area is defined in Table (1), and represents a maximum exposure limit averaged over a 30 minute period. The MPE limit of the Occupational/ Controlled Area is defined in Table (2), and represents a maximum exposure limit averaged over a 6 minute period. The purpose of this report is to provide an analysis of the aircraft station power flux densities, and to compare those levels to the specified MPE limits.

This report provides predicted density levels in the near field, far field, transition region, and main reflector surface area.

MPE Limits for General Population/Uncontrolled Area

Frequency Range (MHz)	*Power Density (mW/cm^2)*
1500 – 100,000	1.0

Table 1

MPE Limits for Occupational/Controlled Area

Frequency Range (MHz)	*Power Density (mW/cm^2)*
1500 – 100,000	5.0

Table 2

Table 3 contains formulas, equations and parameters that were used in determining the Power Flux Density levels for the MELCO:

Data Type	Data Symbol	Data Formula	Data Value	Unit of Measure
Power Input	P	Input	23	W
Antenna Size	D	Input	0.65	m
Antenna Area	A	$A = \frac{\pi D^2}{4}$	0.1274	m^2
Subreflector Size	Sub	Input	N/A	cm
Subreflector Area	A_{sub}	$A_{sub} = \frac{\pi D_{Sub}^{\ 2}}{4}$	N/A	cm^2
Gain dBi	G_{dbi}	Input	33.1	dBi
Gain Factor	G	$G = 10^{GdBi/10}$	2041.74	Gain Factor
Frequency	f	Input	14250	MHz
Wavelength	λ	$299.79 / f$	0.021038	m
Aperture Efficiency	η	$\eta = \frac{G\lambda^2}{4\pi A}$	.56	n/a
Pi	π	Input	3.14159	Numeric
Speed of Light	C	Input	299,792,458	m/sec
Conversion W to mW	mW	mW = $W \times 1000$	n/a	n/a
Conversion M to cm	cm	cm = $m \times 100$	n/a	n/a
Conversion M^2 to cm^2	cm^2	$cm^2 = m^2 \times 10000$	n/a	n/a
Conversion W/M^2 to mW/cm^2	mW/cm^2	$mW/cm^2 = \frac{W}{10m^2}$	n/a	n/a

Table 3

1. Far Field Analysis

The distance to the far field can be calculated using the following formula:

$$R_{ff} = \frac{0.6D^2}{\lambda} = \text{12.05 Meters}$$

The power density in the far field can be calculated using the following formula. Note: this formula requires the use of power in milliwatts and far field distance in centimeters, or requires a post calculation conversion from W/M^2:

$$S_{ff} = \frac{PG}{4\pi R_{ff}^{\;2}}$$ = 2.574 mW/cm^2

2. Near Field Analysis

The extent of the Near Field region can be calculated using the following formula:

$$R_{nf} = \frac{D^2}{4\lambda}$$ = 5.02 Meters

The power density of the near field can be calculated using the following formula. Note: this formula requires the use of power in milliwatts and diameter in centimeters, or requires a post calculation conversion from W/M^2:

$$S_{nf} = \frac{16\eta P}{\pi D^2}$$ = 15.650 mW/cm^2

3. Transition Region Analysis

The transition region extends from the end of the near field out to the beginning of the far field. The power density in the transition region decreases inversely with distance from the antenna, while power density in the far-field decreases inversely with the square of the distance. However the power density in the transition region will not exceed the density in the near field, and can be calculated for any point in the transition region (R), using the following formula. **For the purposes of this analysis we calculated the transition region range where the occupational hazard limit of 5 mW/cm^2 would be reached, thus establishing a keep out range for occupational workers.**

$$S_t = \frac{S_{nf} R_{nf}}{R}$$ = **5 mW/cm^2 = 10.75 Meters**

4. Main Reflector Surface Area Analysis

The maximum power density at the antenna surface area can be calculated using the following formula. Note: this formula requires the use of Power in milliwatts and Area in centimeters squared, or requires a post calculation conversion from W/M^2.

$$S_{surface} = \frac{4P}{A}$$ = 72.214 mW/cm^2

Tables 4 and 5 present a summary of the radiation hazard findings on the MELCO terminal for both the General Population/Uncontrolled Area, as well as the Occupational/Controlled area environments.

MPE Limits for General Population/Uncontrolled Area

Area	***Range Meters***	***Power Density (mW/cm^2)***	***Finding***
Far Field	12.05	2.574 mW/cm^2	Potential Hazard
Near Field	5.02	15.650 mW/cm^2	Potential Hazard
Transition Region	5.02 – 12.05	15.650 mW/cm^2	Potential Hazard
Main Reflector Surface	N/A	72.214 mW/cm^2	Potential Hazard

Table 4

MPE Limits for Occupational/Controlled Area

Area	***Range Meters***	***Power Density (mW/cm^2)***	***Finding***
Far Field	12.05	2.574 mW/cm^2	Meets FCC Requirement
Near Field	5.02	15.650 mW/cm^2	Potential Hazard
Transition Region	5.02 – 12.05	15.650 mW/cm^2	Potential Hazard
Main Reflector Surface	N/A	72.214 mW/cm^2	Potential Hazard

Table 5

5. Summary

This document presents the radiation hazard for the Boeing Broadband System Network incorporating the MELCO antenna and the maximum EIRP of 46.7 dBW. The radiation hazard is divided into two cases; General Public and Occupational. The General Public risk is mitigated by the placement of the antenna on the top of the aircraft, which is not accessible to the general public. The Occupational risk will be controlled by turning the system off prior to performing any antenna maintenance, accessing the top of the aircraft near the antenna, or operating personnel lifts or other similar equipment in the vicinity of the antenna hazard zone defined in this report.

This report presents an analysis of the non-ionizing radiation levels for a TECOM antenna system.

The calculations used in this analysis were derived from and comply with the procedures outlined in the Federal Communications Commission, Office of Engineering and Technology, Bulletin Number 65, which establishes guidelines for human exposure to Radio Frequency Electromagnetic Fields. Bulletin 65 defines exposure levels in two separate categories, the General Population/Uncontrolled Areas limits, and the Occupational/Controlled Area limits. The Maximum Permissible Exposure (MPE) limit of the General Population/ Uncontrolled Area is defined in Table (1), and represents a maximum exposure limit averaged over a 30 minute period. The MPE limit of the Occupational/ Controlled Area is defined in Table (2), and represents a maximum exposure limit averaged over a 6 minute period. The purpose of this report is to provide an analysis of the aircraft station power flux densities, and to compare those levels to the specified MPE limits.

This report provides predicted density levels in the near field, far field, transition region, and main reflector surface area.

MPE Limits for General Population/Uncontrolled Area

Frequency Range (MHz)	*Power Density (mW/cm^2)*
1500 – 100,000	1.0

Table 1

MPE Limits for Occupational/Controlled Area

Frequency Range (MHz)	*Power Density (mW/cm^2)*
1500 – 100,000	5.0

Table 2

Table 3 contains formulas, equations and parameters that were used in determining the Power Flux Density levels for the TECOM:

Data Type	Data Symbol	Data Formula	Data Value	Unit of Measure
Power Input	P	Input	17	W
Antenna Size	D	Input	0.65	m
Antenna Area	A	Input	0.1137	m^2
Subreflector Size	Sub	Input	N/A	cm
Subreflector Area	A_{sub}	$A_{sub} = \frac{\pi D_{Sub}^{2}}{4}$	N/A	cm^2
Gain dBi	G_{dbi}	Input	32.5	dBi
Gain Factor	G	$G = 10^{GdBi/10}$	1778.28	Gain Factor
Frequency	f	Input	14250	MHz
Wavelength	λ	$299.79 / f$	0.021038	m
Aperture Efficiency	η	$\eta = \frac{G\lambda^2}{4\pi A}$	.55	n/a
Pi	π	Input	3.14159	Numeric
Speed of Light	C	Input	299,792,458	m/sec
Conversion W to mW	mW	mW = $W \times 1000$	n/a	n/a
Conversion M to cm	cm	cm = $m \times 100$	n/a	n/a
Conversion M^2 to cm^2	cm^2	$cm^2 = m^2 \times 10000$	n/a	n/a
Conversion W/M^2 to mW/cm^2	mW/cm^2	$mW/cm^2 = \frac{W}{10m^2}$	n/a	n/a

Table 3

1. Far Field Analysis

The distance to the far field can be calculated using the following formula:

$$R_{ff} = \frac{0.6D^2}{\lambda} = 12.05 \text{ Meters}$$

The power density in the far field can be calculated using the following formula. Note: this formula requires the use of power in milliwatts and far field distance in centimeters, or requires a post calculation conversion from W/M^2:

$$S_{ff} = \frac{PG}{4\pi R_{ff}^{2}} = 1.657 \text{ mW/cm}^2$$

2. Near Field Analysis

The extent of the Near Field region can be calculated using the following formula:

$$R_{nf} = \frac{D^2}{4\lambda} = \quad 5.02 \text{ Meters}$$

The power density of the near field can be calculated using the following formula. Note: this formula requires the use of power in milliwatts and diameter in centimeters, or requires a post calculation conversion from W/M^2:

$$S_{nf} = \frac{16\eta P}{\pi D^2} = \quad 11.288 \text{ mW/cm}^2$$

3. Transition Region Analysis

The transition region extends from the end of the near field out to the beginning of the far field. The power density in the transition region decreases inversely with distance from the antenna, while power density in the far-field decreases inversely with the square of the distance. However the power density in the transition region will not exceed the density in the near field, and can be calculated for any point in the transition region (R), using the following formula. **For the purposes of this analysis we calculated the transition region range where the occupational hazard limit of 5 mW/cm^2 would be reached, thus establishing a keep out range for occupational workers.**

$$S_t = \frac{S_{nf} R_{nf}}{R}$$

at **5 mW/cm^2 R = 11.34 m**

4. Main Reflector Surface Area Analysis

The maximum power density at the antenna surface area can be calculated using the following formula. Note: this formula requires the use of Power in milliwatts and Area in centimeters squared, or requires a post calculation conversion from W/M^2.

$$S_{surface} = \frac{4P}{A} = \quad 59.807 \text{ mW/cm}^2$$

Tables 4 and 5 present a summary of the radiation hazard findings on the TECOM terminal for both the General Population/Uncontrolled Area, as well as the Occupational/Controlled area environments.

MPE Limits for General Population/Uncontrolled Area

Area	Range Meters	Power Density (mW/cm^2)	Finding
Far Field	12.05	1.657 mW/cm^2	Potential Hazard
Near Field	5.02	11.288 mW/cm^2	Potential Hazard
Transition Region	5.02 – 12.05	11.288 mW/cm^2	Potential Hazard
Main Reflector Surface	N/A	59.807 mW/cm^2	Potential Hazard

Table 4

MPE Limits for Occupational/Controlled Area

Area	Range Meters	Power Density (mW/cm^2)	Finding
Far Field	12.05	1.657 mW/cm^2	Meets FCC Requirement
Near Field	5.02	11.288 mW/cm^2	Potential Hazard
Transition Region	5.02 – 12.05	11.288 mW/cm^2	Potential Hazard
Main Reflector Surface	N/A	59.807 mW/cm^2	Potential Hazard

Table 5

5. Summary

This document presents the radiation hazard for the Boeing Broadband System Network incorporating the TECOM antenna and the maximum EIRP of 44.8 dBW. The radiation hazard is divided into two cases; General Public and Occupational. The General Public risk is mitigated by the placement of the antenna on the top of the aircraft, which is not accessible to the general public. The Occupational risk will be controlled by turning the system off prior to performing any antenna maintenance, accessing the top of the aircraft near the antenna, or operating personnel lifts or other similar equipment in the vicinity of the antenna hazard zone defined in this report.