



South Pole Power Density Calculations in X-band

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United States Antarctic Program

Agenda



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Problem Definition

- The power density from the South Pole X-band antennas aiming to B7 (104°E) or B13 (112° West) satellites are expected to be **10 nW/m²** (-80 dBW/m²) or lower when it is received in the South Pole Telescope area.
- The RF power is obtained from the link budgets calculations and selecting the carrier that requires the maximum EIRP (worst case).
- The antenna gain is obtained from the antenna radiation patterns for the 4.2 m diameter antenna at transmit mid-band frequency (8.15 GHz) and TX RHCP.
- The power density is calculated using the channel with the higher or maximum EIRP.

Overview of Formulas

The formula to calculate the power density will be the following:

$$PD = \frac{EIRP}{4\pi R^2} [W/m^2]$$

Where:

PD = Power Density [W/m^2]

EIRP = Effective Isotropic Radiated Power [W]

R = Distance to location where the PD will be calculated [m]

For the power density formula in dB:

$$PD = EIRP - 10 \log (4\pi R^2) [dBW/m^2]$$

Where:

PD = Power Density [dBW/m^2]

EIRP = Effective Isotropic Radiated Power [dBW]

R = Distance to location where the PD will be calculated [m]

Notes:

$$EIRP = \frac{TxGain \times RF \text{ Output}}{RF \text{ Loss}} [W]$$

$$EIRP = TxGain + RF \text{ Output} - RF \text{ Losses [dBW]}$$

The atmospheric losses are not considered

Overview of Formulas (cont.)

Another way to calculate the power density is the following:

$$PD = EIRP - L_p + Gr1m^2 \text{ [dBW/m}^2\text{]}$$

Where:

$$PD = \text{Power Density [dBW/m}^2\text{]}$$

$$EIRP = \text{Effective Isotropic Radiated Power} = G_{Tx} + \text{RF power} - \text{cable/waveguide loss [dBW]}$$

$$L_p = \text{path loss} = 10 \log \left(\frac{4\pi R}{\lambda} \right)^2 \text{ [dB]}$$

$$Gr1m^2 = 1 \text{ m}^2 \text{ antenna gain at the operating frequency [dBi]}$$

$$\text{For 8.15 GHz, } Gr1m^2 = 39.637 \text{ dBi}$$

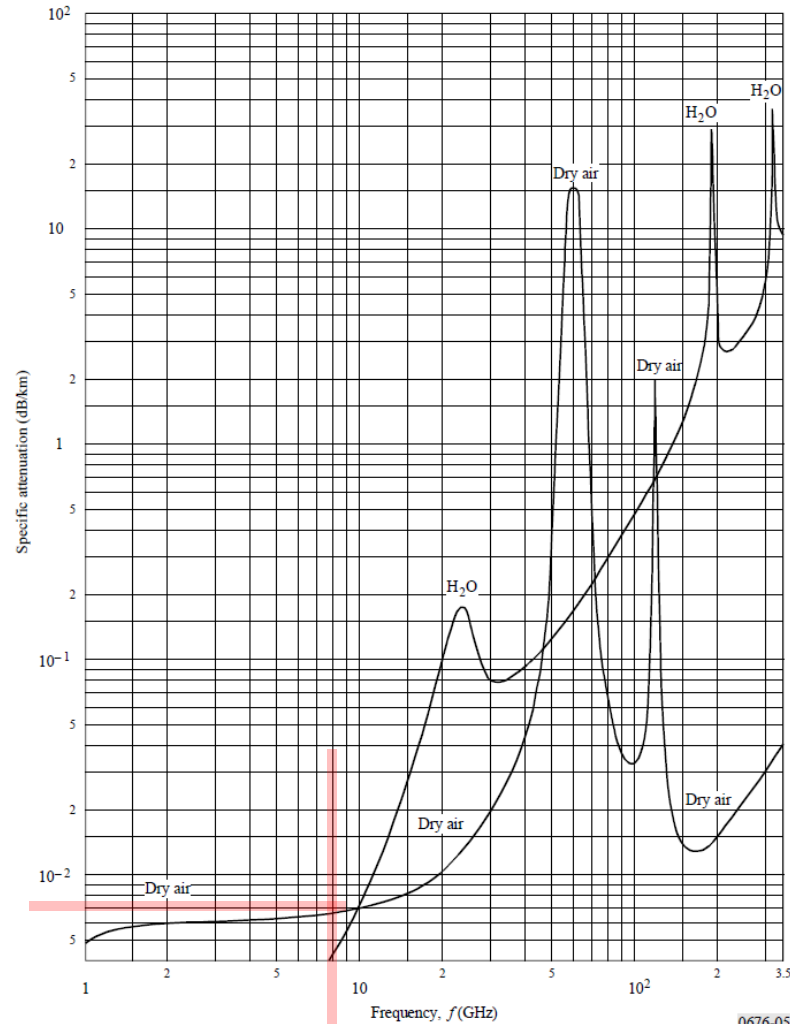
Notes:

The atmospheric losses are not considered

The Atmospheric Losses



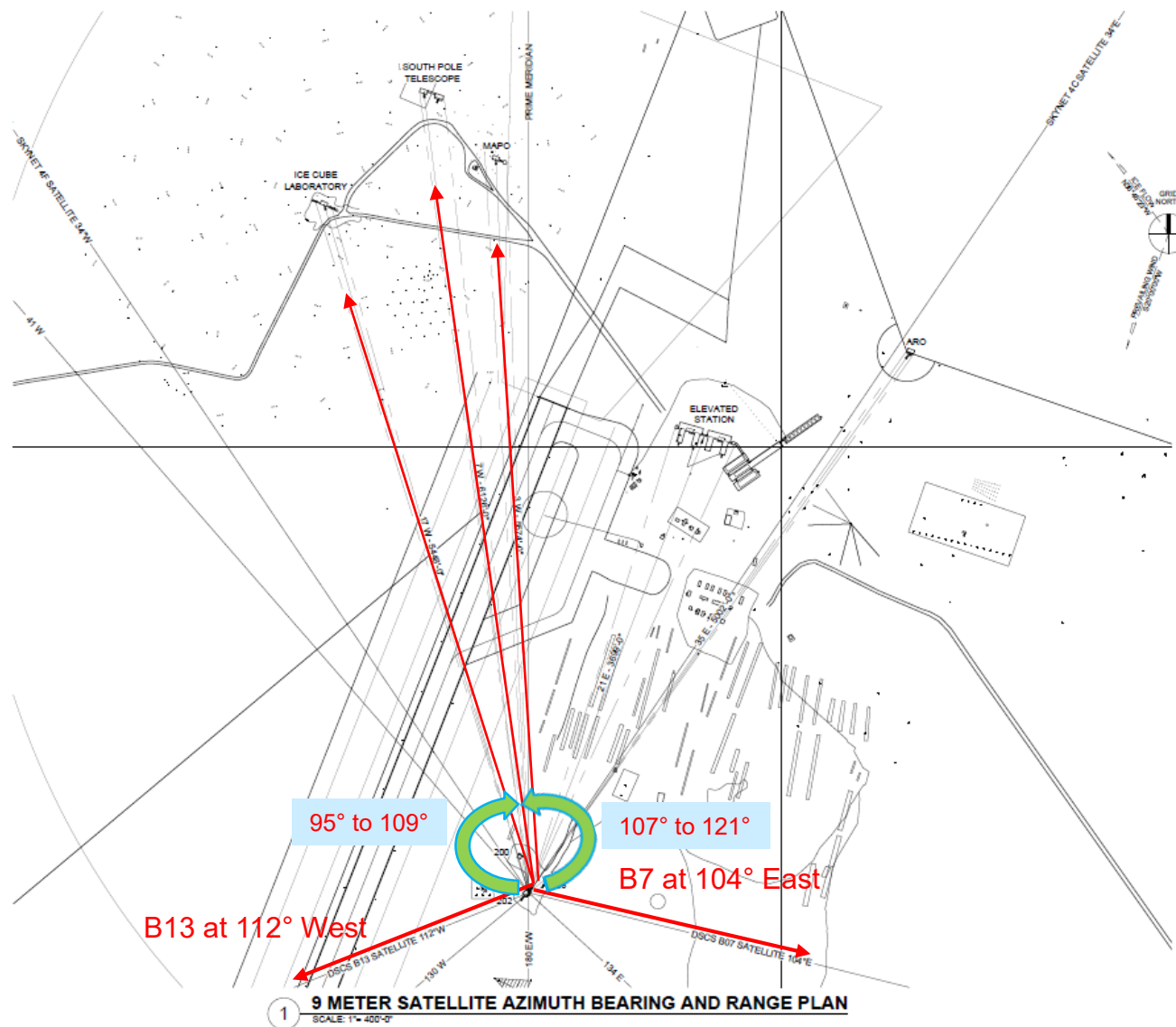
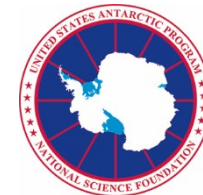
Specific attenuation due to atmospheric gases



$$7 \times 10^{-2} = 0.07 \text{ dB/km}$$

Pressure: 1 013 hPa
Temperature: 15° C
Water vapour: 7.5 g/m³

South Pole Site Map



Sidelobe Angle Calculations

- The azimuth angle for the antenna aiming to the DSCS B7 satellite is 104° East in azimuth.
- The azimuth angle for the antenna aiming to the DSCS B13 satellite is 112° West in azimuth.
- The South MAPO Telescope is 3° West in azimuth at 5,574 ft (1,699.4 m) from 202 Bldg.
- The South Pole Telescope is 7° West in azimuth at 6,126 ft (1,867.7 m) from 202 Bldg.
- The ICE Cube Laboratory is 17° West in azimuth at 5,448 ft (1,661 m) from 202 Bldg.
- DSCS B7 (104° East) Satellite:
 - MAPO: $104^\circ + 3^\circ = 107^\circ$ to the left of the antenna.
 - South Pole Telescope: $104^\circ + 7^\circ = 111^\circ$ to the left of the antenna.
 - Ice Cube Lab: $104^\circ + 17^\circ = 121^\circ$ to the left of the antenna.
- DSCS B13 (112° West) Satellite:
 - MAPO: $112^\circ - 3^\circ = 109^\circ$ to the right of the antenna.
 - South Pole Telescope: $112^\circ - 7^\circ = 105^\circ$ to the right of the antenna.
 - Ice Cube Lab: $112^\circ - 17^\circ = 95^\circ$ to the right of the antenna.

Antenna Sidelobe Gain



- The TX Gain from 48° to 180° from the main beam should be -10 dBi or less according the Section 25.209 (antenna performance standard) from the Federal Communications Commission (FCC) for earth station antennas used for transmission from an earth station to a geostationary satellite orbit.

Federal Communications Commission

§ 25.209 Antenna performance standards.

(a) The gain of any antenna to be employed in transmission from an earth station in the geostationary satellite orbit fixed-satellite service (GSO FSS) shall lie below the envelope defined as follows:

(1) In the plane of the geostationary satellite orbit as it appears at the particular earth station location:

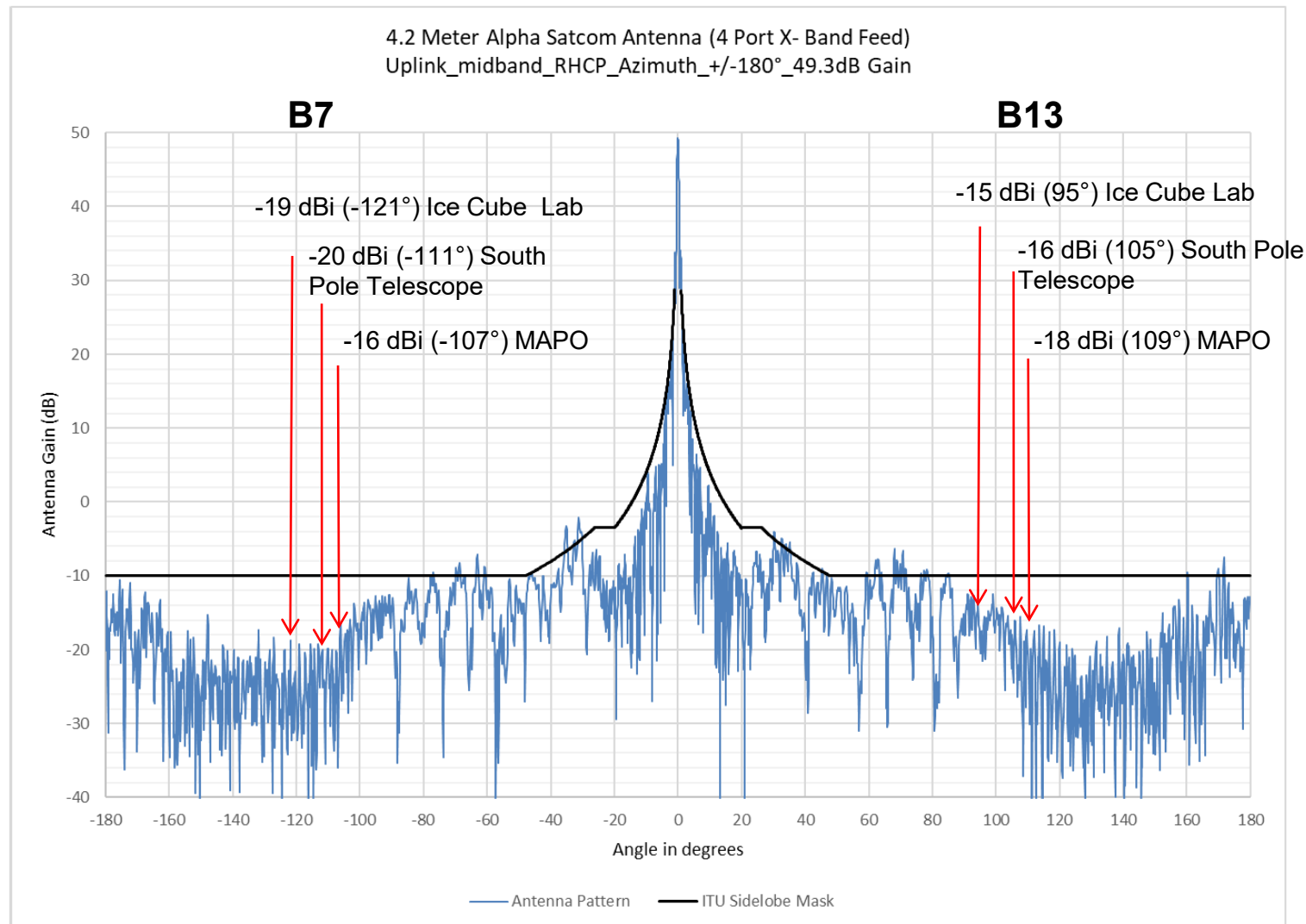
$$29-25 \log_{10} (\text{Theta}) \text{ dBi } 1^\circ \leq \text{Theta} \leq 7^\circ \\ +8 \text{ dBi } 7^\circ < \text{Theta} \leq 9.2^\circ$$

$$32-25 \log_{10} (\text{Theta}) \text{ dBi } 9.2^\circ < \text{Theta} \leq 48^\circ$$

$$-10 \text{ dBi } 48^\circ < \text{Theta} \leq 180^\circ$$

where Theta is the angle in degrees from the axis of the main lobe, and dBi refers to dB relative to an isotropic radiator. For the purposes of this section, the peak gain of an individual sidelobe may not exceed the envelope defined above for Theta between 1.0 and 7.0 degrees. For Theta greater than 7.0 degrees, the envelope may be exceeded by no more than 10% of the sidelobes, provided no individual sidelobe exceeds the gain envelope given above by more than 3 dB.

Radiation Patterns for a 4.2 m Diameter Antenna







Power Density Calculation from a 4.2 m Antenna/190 watts to South Pole Telescope - B7 (Delta Az Angle 111°)

X-band Power Density Limit			X-band Satcom				Another Calculation Option			
							Direct Pointing			
Frequency	Power Density Limit [nW/m2]	Power Density Limit [dBW/m2]								
8.15	10	-80	X-Band							
			Direct Pointing							
Distance [m]	Equipment	Cable Losses [dB]	Tx Power				190 Watts	EIRP =	71.01	dBW
1867.7	X-Band E/S	1	Tx Pwr - Cable Loss		21.8	dBW	150.922 W			
			Antenna Gain		49.22	dB	83634.51	Ratio		
C	299792458	m/s	Distance		1867.7	m	1867.7	m		
Frequency	8.15	GHz	Power Density @ TX Freq.				0.287949	W/m^2		
Ant. Diameter	4.2	m	Power Density @ TX Freq.				-5.407	dBW/m^2		
			83634.506	dB	Out of Band Filtering		60	dB		
			49.22	dB	Power Density @ Out of TX Band		-65.407	dBW/m^2		
Gain Decrease		69.22	dB							
Out of Band Filter		60	dB							
			Antenna Sidelobe							
Satellite	B7		Tx Power				190 Watts	EIRP =	1.79	dBW
Delta Az Angle	111°		Tx Pwr - Cable Loss		21.8	dBW	150.9224 W			
			Antenna Gain		-20.00	dB	0.010009	Ratio	Antenna Sidelobe Gain	
Transponder 4	60	MHz	Distance		1867.7	m	1867.7	m		
			Power Density @ TX Freq.				3.45E-08	W/m^2		
			Power Density @ TX Freq.				-74.627	dBW/m^2		
			Out of Band Filtering				60	dB		
			Power Density @ Out of TX Band				-134.627	dBW/m^2		



Power Density Calculation from a 4.2 m Antenna/ 190 watts to Ice Cube Lab – B7 (Delta Az Angle 121°)

X-band Power Density Limit			X-band Satcom				Another Calculation Option				
Frequency	Power Density Limit [nW/m2]	Power Density Limit [dBW/m2]					Direct Pointing				
8.15	10	-80	X-Band								
			Direct Pointing								
Distance [m]	Equipment	Cable Losses [dB]	Tx Power		190 Watts	EIRP =	71.01	dBW	Distance	1661 m	
1661	X-Band E/S	1	Tx Pwr - Cable Loss	21.8	dBW	150.922	W		Freq	8.15 GHz	
			Antenna Gain	49.22	dB	83634.51	Ratio		λ	0.036784 m	
C	299792458	m/s	Distance	1661	m	1661	m		Ant. Radius	0.564190 m	
Frequency	8.15	GHz	Power Density @ TX Freq.			0.364074	W/m^2		Area	1.000000 m2	
Ant. Diameter	4.2	m	Power Density @ TX Freq.			-4.388	dBW/m^2		1 m2 Ant. Gain	9287.176 Ratio	
		83634.506	dB			60	dB		1 m2 Ant. Gain	39.679 dBi	
		49.22	dB			-64.388	dBW/m^2		Loss	3.21983E+11 Ratio	
Gain Decrease		68.22	dB						Loss	115.078 dB	
Out of Band Filter		60	dB						EIRP	71.01 dBW	
			Antenna Sidelobe				Rx Power				-44.07 dBW
Satellite	B7		Tx Power			190 Watts	EIRP =	2.79	dBW	Power Density	-4.388 dBW/m^2
Delta Az Angle	121°		Tx Pwr - Cable Loss	21.8	dBW	150.9224	W			Out of Band Filter	60.00 dB
			Antenna Gain	-19.00	dB	0.0126	Ratio	Antenna Sidelobe Gain		Power Density @ Out TX Band	-64.388 dBW/m^2
Transponder 4	60	MHz	Distance	1661	m	1661	m			Antenna Sidelobe	
			Power Density @ TX Freq.			5.49E-08	W/m^2			Distance	1661 m
			Power Density @ TX Freq.			-72.608	dBW/m^2			Freq	8.15 GHz
			Out of Band Filtering			60	dB			λ	0.036784 m
			Power Density @ Out of TX Band			-132.608	dBW/m^2			Ant. Radius	0.564190 m
									Area	1.000000 m2	
									1 m2 Ant. Gain	9287.176 Ratio	
									1 m2 Ant. Gain	39.679 dBi	
									Loss	3.21983E+11 Ratio	
									Loss	115.078 dB	
									EIRP	2.79 dBW	
									Rx Power	-112.29 dBW	
									Power Density	-72.608 dBW/m^2	
									Out of Band Filter	60.00 dB	
									Power Density @ Out TX Band	-132.608 dBW/m^2	



Power Density Calculation from a 4.2 m Antenna/ 110 watts to MAPO – B13 (Delta Az Angle 109°)

X-band Power Density Limit			X-band Satcom							Another Calculation Option			
										Direct Pointing			
Frequency	Power Density Limit [nW/m2]	Power Density Limit [dBW/m2]											
8.15	10	-80	X-Band										
			Direct Pointing										
Distance [m]	Equipment	Cable Losses [dB]	Tx Power				110	Watts	EIRP =	68.64	dBW		
1699.4	X-Band E/S	1	Tx Pwr - Cable Loss		19.4	dBW	87.376	W					
			Antenna Gain		49.22	dBi	83634.51	Ratio					
C	299792458	m/s	Distance		1699.4	m	1699.4	m					
Frequency	8.15	GHz	Power Density @ TX Freq.				0.201362	W/m^2					
Ant. Diameter	4.2	m	Power Density @ TX Freq.				-6.960	dBW/m^2					
		83634.506	dBi	Out of Band Filtering				60	dB				
		49.22	dBi	Power Density @ Out of TX Band				-66.960	dBW/m^2				
Gain Decrease		67.22	dB										
Out of Band Filter		60	dB										
			Antenna Sidelobe										
Satellite	B13		Tx Power				110	Watts	EIRP =	1.42	dBW	Antenna Sidelobe	
Delta Az Angle	109		Tx Pwr - Cable Loss		19.4	dBW	87.37611	W				Distance	
			Antenna Gain		-18.00	dBi	0.015863	Ratio	Antenna Sidelobe Gain			1699.4 m	
Transponder 2	75	MHz	Distance		1699.4	m	1699.4	m				Freq	
			Power Density @ TX Freq.				3.82E-08	W/m^2				λ	
			Power Density @ TX Freq.				-74.180	dBW/m^2				Ant. Radius	
			Out of Band Filtering				60	dB				Area	
			Power Density @ Out of TX Band				-134.180	dBW/m^2				1 m2 Ant. Gain	
												9287.176 Ratio	
												1 m2 Ant. Gain	
												39.679 dBi	
												Loss	
												3.37043E+11 Ratio	
												Loss	
												115.277 dB	
												EIRP	
												68.64 dBW	
												Rx Power	
												-46.64 dBW	
												Power Density	
												-6.960 dBW/m^2	
												Out of Band Filter	
												60.00 dB	
												Power Density @ Out TX Band	
												-66.960 dBW/m^2	



Power Density Calculation from a 4.2 m Antenna/110 watts to South Pole Telescope – B13 (Delta Az Angle 105°)

				<u>X-band Satcom</u>								<u>Another Calculation Option</u>		
X-band Power Density Limit														
Frequency	Power Density Limit [nW/m2]	Power Density Limit [dBW/m2]												
8.15	10	-80	X-Band											
			Direct Pointing											
Distance [m]	Equipment	Cable Losses [dB]	Tx Power				110	Watts	EIRP =	68.64	dBW			
1867.7	X-Band E/S	1	Tx Pwr - Cable Loss		19.4	dBW	87.376	W						
			Antenna Gain		49.22	dB	83634.51	Ratio						
C	299792458	m/s	Distance		1867.7	m	1867.7	m						
Frequency	8.15	GHz	Power Density @ TX Freq.				0.166707	W/m^2						
Ant. Diameter	4.2	m	Power Density @ TX Freq.				-7.780	dBW/m^2						
		83634.506	dB	Out of Band Filtering			60	dB						
		49.22	dB	Power Density @ Out of TX Band			-67.780	dBW/m^2						
Gain Decrease		65.22	dB											
Out of Band Filter		60	dB											
			Antenna Sidelobe											
Satellite	B13			Tx Power				110	Watts	EIRP =	3.42	dBW		
Delta Az Angle	105			Tx Pwr - Cable Loss		19.4	dBW	87.37611	W					
				Antenna Gain		-16.00	dB	0.025141	Ratio	Antenna Sidelobe Gain				
Transponder 2	75	MHz	Distance		1867.7	m	1867.7	m						
				Power Density @ TX Freq.				5.01E-08	W/m^2					
				Power Density @ TX Freq.				-73.000	dBW/m^2					
				Out of Band Filtering				60	dB					
				Power Density @ Out of TX Band				-133.000	dBW/m^2					
			</											



Power Density Calculation from a 4.2 m Antenna/ 110 watts to Ice Cube Lab – B13 (Delta Az Angle 95°)

X-band Power Density Limit			X-band Satcom						Another Calculation Option			
									Direct Pointing			
Frequency	Power Density Limit [nW/m2]	Power Density Limit [dBW/m2]										
8.15	10	-80	X-Band									
			Direct Pointing									
Distance [m]	Equipment	Cable Losses [dB]	Tx Power		110	Watts	EIRP =	68.64	dBW	Distance	1661 m	
1661	X-Band E/S	1	Tx Pwr - Cable Loss		19.4	dBW	87.37611	W		Freq	8.15 GHz	
			Antenna Gain		49.22	dBi	83634.51	Ratio		λ	0.036784 m	
C	299792458	m/s	Distance		1661	m	1661	m		Ant. Radius	0.564190 m	
Frequency	8.15	GHz	Power Density @ TX Freq.				0.21078	W/m^2		Area	1.000000 m2	
Ant. Diameter	4.2	m	Power Density @ TX Freq.				-6.762	dBW/m^2		1 m2 Ant. Gain	9287.176 Ratio	
		83634.506	dBi	Out of Band Filtering			60	dB		1 m2 Ant. Gain	39.679 dBi	
		49.22	dBi	Power Density @ Out of TX Band			-66.762	dBW/m^2		Loss	3.21983E+11 Ratio	
Gain Decrease		64.22	dB							Loss	115.078 dB	
Out of Band Filter		60	dB							EIRP	68.64 dBW	
			Antenna Sidelobe								Rx Power	-46.44 dBW
Satellite	B13		Tx Power		110	Watts	EIRP =	4.42	dBW	Power Density	-6.762 dBW/m^2	
Delta Az Angle	95		Tx Pwr - Cable Loss		19.4	dBW	87.37611	W		Out of Band Filter	60.00 dB	
			Antenna Gain		-15.00	dBi	0.031651	Ratio		Power Density @ Out TX Band	-66.762 dBW/m^2	
Transponder 2	75	MHz	Distance		1661	m	1661	m		Antenna Sidelobe		
			Power Density @ TX Freq.				7.98E-08	W/m^2		Distance	1661 m	
			Power Density @ TX Freq.				-70.982	dBW/m^2		Freq	8.15 GHz	
			Out of Band Filtering				60	dB		λ	0.036784 m	
			Power Density @ Out of TX Band				-130.982	dBW/m^2		Ant. Radius	0.564190 m	
											Area	1.000000 m2
											1 m2 Ant. Gain	9287.176 Ratio
											1 m2 Ant. Gain	39.679 dBi
											Loss	3.21983E+11 Ratio
											Loss	115.078 dB
											EIRP	4.42 dBW
											Rx Power	-110.66 dBW
											Power Density	-70.982 dBW/m^2
											Out of Band Filter	60.00 dB
											Power Density @ Out TX Band	-130.982 dBW/m^2

Power Density Calculations Results

- **4.2 m Diameter Antenna (190 watts) – B7**

RF Power 190 watts

-107° Sidelobe (MAPO):

-69.81 dBW/m² In band

-129.81 dBW/m² Out of band (60 dB filter)

-111° Sidelobe (South Pole Telescope):

-74.63 dBW/m² In band

-134.63 dBW/m² Out of band (60 dB filter)

-121° Sidelobe (Ice Cube Lab):

-72.61 dBW/m² In band

-132.61 dBW/m² Out of band (60 dB filter)

- **4.2 m Diameter Antenna (110 watts) – B13**

RF Power 110 watts

109° Sidelobe (MAPO):

-74.18 dBW/m² In band

-134.18 dBW/m² Out of band (60 dB filter)

105° Sidelobe (South Pole Telescope):

-73.00 dBW/m² In band

-133.00 dBW/m² Out of band (60 dB filter)

95° Sidelobe (Ice Cube Lab):

-70.98 dBW/m² In band

-130.98 dBW/m² Out of band (60 dB filter)

Conclusions

- The calculated power densities from the 4.2 m diameter antenna in band for the sidelobe beams are between 100 nW/m^2 (-70 dBW/m^2) and 31.62 nW/m^2 (-75 dBW/m^2) for B7 (104° E) satellite.
- The calculated power densities from the 4.2 m diameter antenna in band for the sidelobe beams are between 79.4 nW/m^2 (-71 dBW/m^2) and 39.81 nW/m^2 (-74 dBW/m^2) for B13 (112° W) satellite.
- The calculated power densities from the 4.2 m diameter antenna for out of band for the sidelobe beams are lower than 10 nW/m^2 (-80 dBW/m^2) for B7 (104° E) and B13 (112° W) satellites.