AMSAT / IARU Annotated Link Model System

Version: 2.5.5

Organization: Hawaii Space Flight Laboratory

Project: NEUTRON1

Developed by: Jan A. King, W3GEY/VK4GEY With Editorial Assistance and Support from Ralph Wallio, WΦRPK; Ignacio Mas; Lou McFadin, W5DID; Jeff Capehart, W4UFL; Michelle Denise, W5NYV, Kelby Davis, AD7VO

Approvals:

NOTE #1: Com. System Engineer: Enter Name of Communications Engineer: **Isaac Rodrigues** — X Com. Eng. (NOTE #7:)

NOTE #2: Project Manager: Enter Name of Project Manager: **Lloyd French** — P.M.

NOTE #3: Orbit Type: **Low Earth Orbit Scientific Satellite** / **LEO**

NOTE #4: Model Under Investigation: **Medium Gain Antenna on S/C; Medium Gain Antenna at E.S.** / **Small Satellite**

NOTE #5: Model/Case No./Rev No.: **LinkBudget-ISIS_TRXVU/N1-TEL-DOC-000-013/2.5.5** — Config. Control

Date Data Last Modified: **2019 Feburary 22** — Document Not Released (LINK MODEL STATUS)

NOTE #6 Date W/S Formulas Last Modified: **2019 Feburary 22** — NOTE #8:

Introduction, Instructions for Use, References, Revisions: NEUTRON1 2019 Feburary 22

Introduction:

This spreadsheet system is an attempt to provide a new kind of learning tool. It is intended, clearly, to be a working link model in order to allow satellite system designers to design and then document fully the RF radio links associated with Command (uplink) and Telemetry (downlink) equipment. It is, however, also intended to be a tutorial on the RF portion of a satellite system. The model makes liberal use of "pop-up" notes and "tools" to enhance the understanding (and hopefully the knowledge) of the Link Model Operator (that's you). After you use the model for awhile, let me know if I have been successful. - Jan A. King, W3GEY and VK4GEY; w3gey@amsat.org

Instructions for Use:

Colors: Colors are used in the link model to make it easier to find data and to protect the link model from crashing. Many of the worksheets are interconnected in that equations in one W/S refer forward or back to data located in other worksheets. Loss of this connection could be critical. Also, the cells are not yet protected (and may never be) as the system has not yet been finalized. Color can be used to provide "coded" messages to the link model operator's brain, once it has been used for awhile. This has been found by the designer to be fairly effective (at least with his brain). Color is used for both the text and the cell background. Some colors have been picked for large field areas where it is not so nice to have the Excel cell grid structure showing. Typically, light grey light green light yellow or white are used this way. These colors have been found by our staff psychologist to have a relaxing effect on the operator. Now let's look at the important uses of color:

NOTE: This is a "pop-up" note. You will see a lot of single cells throughout the model that look like this. Using your mouse, place your cursor on the cell. You don't need to click. A note will pop up. These are either local instructions on how to enter data or use data or some form of training note. You will find that some notes are somewhat larger than the screen. I've tried hard to avoid this, but I haven't been entirely successful. The problem with this is that if you scroll to see the rest of the note and if the yellow cell scrolls off of the screen then the note will close. Frustration will ensue. There are two solutions: 1) Reduce the scale of the viewing page from 100% (the ususal setting) to 75% or 85%. This should allow you to see all of the note. 2) Alternatively, using the mouse, select from the upper toolbar, "View", "Toolbars", and select the one called "Reviewing". There should now be a checkmark to the left of that option. Now, you should find a new toolbar up above the text area of Excel. The far left icon will say "new comment" if you are making a new one. But, if you move the curser over the far left icon you will notice the pop-up prompt now says "edit cell." Now, move the curser over the "NOTE:" cell and left click then left click on the same far left icon. This will allow you to edit the cell BUT it will also FREEZE the cell in the ON condition. Now, you can move the note around by using the slide bars on the side and bottom of the screen to see all of the note. It's probably a good idea not to modify the note. You can close the note by just moving the cursor to an empty cell somewhere and left clicking. It is suggested that you try this process now with the test note above at Cell [D23]. It's been set up to frustrate you in just such a way as the real notes might do later on.

X.XX This is a data entry cell. The link model operator is expected to enter data. The blue background means it is a critcal data entry cell. It is anticipated that your system's selected value is quite likely to be different than the default value used in the cell when you received this link model.

X.XX This is also a data entry cell. This type of cell may not need to be changed as the value you are likely to use may be the same as the default value.

X.XX This is a cell containing an equation or a constant that should not be changed. **The operator should not modify these cells.** A majority of the link model contains this type of cell.

X.XX or X.XX These are cells containing important but, intermediate results. Two colors were used to provide a slight gradation of importance. The orange color is considered to be a result having slightly more significance than the lighter yellow cell.

X.XX This is a key "bottom line" result. It is a primary output of a particular W/S.

X or **X** or **X** A few cells use conditional fomatting which allow the cell colors to change depending on the outcome of the preceeding calculations. Typically a RED box means the result was not successful in achieving the desired performance. A GREEN box means the result did meet or exceed the desired performance. A YELLOW box means the result achieved the performance threshould but, is considered marginal.

Sub-Title Box A pink box like this is simply a sub-title for a sub-worksheet.

X.XX An olive green box is a location where data has been transferred to this worksheet from another and may be transferred to yet another. No action need be taken here. It's purpose is only so that the operator is aware that the data is being transferred from and to other locations.

Frequency Sometimes an olive green cell will be used to re-emphasize a frequency selection as in the "System Performance Summary" W/S.

Non-Coherent FSK Sometimes a tan color cell is used to denote a selected system condition that is non-numeric.

Gains and Losses: A positive gain or directivity is always experssed as a positive number. Sometimes the value may be seen to have a + in front of it. Gains can also be negative (remember, the gain of an antenna is expressed as $10\log(P/P_{isotropic})$. So, if the gain in a particular direction, is below that of an isotropic radiator, then the gain will be expressed as a negative number in dBi.

Losses in link budgets are commonly found as either positive or negative. A loss, by it's nature, is a negative quantity but, some believe that if the loss is clearly referred to as such in the budget *parameter* column, it can have a positive sign. That is the case in this link budget. All losses are shown as being a positive value. The argument is symantic. The question could be asked, "Is a positive loss a negative? And is a negative loss, positive? The important thing for the link model operator to know when using this modeling system is that the losses are show as positive values **BUT**, in the equations that sum the gains and losses to yield the result, the gains are *added* and the losses are *subtracted*. For example, see the equation in Cell [B11] of the "Uplink" W/S.

Speciality W/S vs. Tools: The first 13 W/Ss are all interconnected, in that they all have equations that make use of data contained in one or more of the other W/Ss. These worksheets, taken together, constitute the link model. The next 5 W/Ss are supplementary to the model and are considered to be *tools*. The important distinction is, that tools *never* produce results that are automatically linked into the model itself, whereas within the first 13 W/Ss there is lots of interlinking going on. The primary process is one where data calculated or selected in one of the S*peciality* W/Ss (e.g., "Receivers") becomes just one entry in either the Uplink or the Downlink budget. The usefulness of a tool is to be able to explore a specific tradeoff without having to worry about that data winding up in the formal Uplink or Downlink pages.

There is one additional and imporatant comment about tools. Within the Speciality W/Ss, there are some embedded tools. The best example of this is in the "Receivers" W/S. Contained in separate sub-tables is a *Noise Figure/Noise Temperature Calculator (Tool)* and a *Ground Station, Antenna or Sky Noise Temperature Calculation Tool*.

Proceeding Through the Model: Starting with the "Title Page" W/S, proceed through each Speciality W/S, adding data, in sequence. Then select the next tab at the bottom of the W/S. The "Uplink", "Downlink" and "System Performance Summary" W/Ss contain the final results of the model. The Tools W/Ss are located beyond the "System Perfomance Summary" W/S and may be explored and used as they may be helpful to you. Any comments you may have on this model will be greatfully received by me. **Thanks!** Jan, VK4GEY.

References:

The following references were used to prepare this link model:

1 A.R.R.L., *The ARRL Antenna Handbook,* American Radio Relay League, 1974, pp. 153-155.

2 Deloraine, E.M., Westman, H.P., Edie, L.C. *Reference Data for Radio Engineers, 3rd Edition*, Federal Telephone & Radio Corp., 1949, pp. 362-396.

3 Feher, Dr. Kamilo, *Digital Communications, Satellite/Earth Station Engineering*, Prentice-Hall Books, 1983, Chapter 4.

4 Ippolito, L.J.Jr., *Radiowave Propagation in Satellite Communications,* Van Norstrand Reinhold Co., 1986, Chapters 3 and 7.

5 Jordan, E.C. (Edit.), *Reference Data for Engineers: Radio, Electronics, Computer, and Communications, 7th Edition*, Howard W. Sams & Co., 1985, pp. 29-26 - 29-37 and pp. 30-03 - 30-11.

6 Martin, W.L., *AMMOS and DSN Support of Earth Orbiting and Deep Space Missions,* Jet Propulsion Laboratory, TMOD Directorate, 1996, p.44-46.

7 Morgan, W.L. and Gordon, G.D., *Principles of Communicaitons Satellites*, John Wiley & Sons, Inc., 1993, Chapter 2 and pp.140-143.

8 Van Wie, D.G. and Roark, R.C., *A New Alert Protocol,* Blue Water Design, LLC*, 2003,* pp. 18-23.

9 Jackson, R.B., *The Canted Turnstile as an Omnidirectional Spacecraft Antenna,* X-712-67-441, NASA/Goddard Space Flight Center, 1967, Entire Document.

Revisions:

The following formal revisons have been made to this Link Model System:

Version:	*Date:*	*Adjustments and/or Modifications Made:*
2.0	1/30/2005	NEW; b-Test Version
2.1	2/7/2005	Revised All "Pop-up" Notes; Corrected some cell colors to improve consistancy; Added reference 9; Corrected cells A19 & D19 in "Uplink" W/S.
2.1.1	2/12/2005	Revised Equation at Cell [B15] of "Uplink Budget" W/S. Index function should use column H values not column C values.
2.1.2	2/21/2005	Modified Data for Monopole Antenna Pattern in Monopole Table in "Antenna Patterns" W/S. Added 3 dB to all Values (0° to 90°)
2.1.3	2/26/2005	Modified "Receviers" W/S. Added loss value for cable D. Modified 2nd Stage to "Communications Receiver" at Ground Station.
2.1.4	2/27/2005	Added Tubo Code Option to "Modulation-Demodulation Method" W/S.
2.2	2/27/2005	Added EZNEC+ and Chart Wizzard Antenna Plots to "Antenna Pattern" W/S.
2.2.1	5/15/2005	Edited Notes in I.I.R.R W/S.
2.2.2	6/23/2005	Edited More Notes Throughout Link Model.
2.3	7/16/2005	Revised Antenna Gain and Antenna Pointing Losses W/Ss to Include a High Gain (Parabolic Reflector) S/C Antenna Option & Iso. Radiator Option.
2.3.1	9/28/2005	Modified Notes at Cells [P135] and [V52] of "Receivers" W/S. Added T_0 reference temperature "readout" at Cell [U56] of "Receivers" W/S.
2.3.2	10/4/2005	Modified Equation at Q62 of "Antenna Gain" W/S. Equation was "=21/(F55/1000)*H62" and now is "=21/((F55/1000)*H62)." TNX Ignacio Mas.
2.4	10/22/2006	Changed "Downlink" to "Uplink" at D22 in "Antenna Gain" W/S. Changed hard coded cells in "Ant. Pointing Losses" W/S for referenced cells. Fixed errors in downlink portion of worksheet. There were several incorrect references. Added NOT
2.5	Not Released	Added HEO, GEO and Deep Space Orbit Capability. Link Model Operator selects options. Separted Orbit and Frequency into two separate pages.
2.5.1	3/6/2008	Repaird Bugs in User #2, Delta Longitude, Range, Azimuth and Earth Central Angle; Thank to Michelle Denise, W5NYV
2.5.2	3/18/2008	Repaired Import of Frequency Values to "Transmitters" and "Receivers" Worksheets; Thanks to Michelle Denise, W5NYV
2.5.3	12/17/2008	In "Atmos. & Ionos. Losses" W/S; temporarily made Atmos. Loss dependent on Manually Set Elevation Angle. This needs more work.
2.5.4	3/11/2014	Revised Beam Roll-off Tool Tab to Include Dish Diameter in Wavelengths and Test for 10 wavelength condition.
2.5.5	10/20/2016	Revised Antenna Polarization Loss (R = 10^(AR/20); Antenna Pointling Loss, Downlink, Ground Station Table: Antenna Gains Corrected; TNX to Kelby Davis, AD7VO

System Orbit Characteristics:

NEUTRON1 — 2019 Feburary 22 — Version: 2.5.5

Orbit Option to be Used in Link Model (LEO, HEO, GEO, Deep Space)

Select Orbit Option: 1 — LEO — **Slant Range:** 1,440 km — Used in Path Loss Calculation

Option No.:	Orbit Type:	Slant Range:	
1	LEO	1439.8	km
2	HEO	41126.8	km
3	GEO	36488.2	km
4	Deep Space	3.150E+08	km

Element Reference Epoch: 2005, 87.50000

Blue = User Data Entry Values
Black = Computed Values (**No Data Entry**)
Red = Key Results
Blue =Critical User Data Entry Values
NOTE: Cells Not Yet Protected

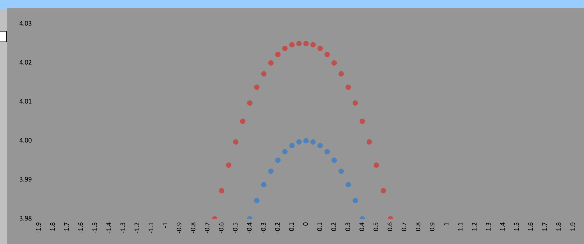
LEO Orbit - Option #1

NOTE:

Low Earth Orbit Properties

Slant Range to Spacecraft vs. Elevation Angle

Parameter:	*Value:*	*Unit:*
Earth Radius:	6,378.14	km
Height of Apogee (ha):	400.0	km
Height of Perigee (hp):	400.0	km
Semi-Major Axis (a):	6,778.1	km
Eccentricity (e):	0.000000	
Inclination (I):	51.60	°
Argument of Perigee (w):	180.0	°
R.A.A.N. (W):	123.70	°
Mean Anomaly (M):	0.00	°
Period:	92.561	minutes
dw/dt:	3.7397	deg./day
dW/dt:	-5.0002	deg./day
dM/dt:	Not Implemented	deg./day
Mean Orbit Altitude:	400.00	km
Mean Orbit Radius:	6,778.14	km
Sun Synchronous Inclination:	97.03	°
Elevation Angle (d):	10.0	°
Slant Range (**S**):	1,439.8	km.



High Earth Orbit (HEO) - Option #2

NOTE:

LEO Orbit Geometry

HEO Orbit Properties

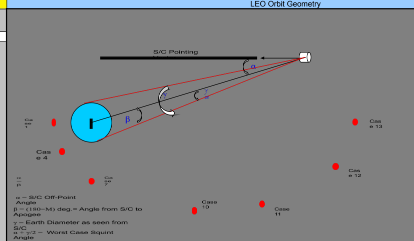
S/C Spinning and NADIR-Pointing at Apogee

Parameter:	*Value:*	*Unit:*
Earth Radius:	6,378.14	km
Height of Apogee:	35,786	km
Height of Perigee:	500	km
Semi-Major Axis (a):	24,521.14	km
Eccentricity (e):	0.719502	
Inclination (I):	7.00	degrees
Argument of Perigee (w):	180.0	degrees
R.A.A.N. (W):	0.00	degrees
Mean Anomaly (M):	180.00	degrees
Period:	636.90	minutes
dw/dt:	0.7542	deg./day
dW/dt:	-0.3814	deg./day

1) To Change Orbit Keplarians Modify **ONLY** Blue Values Above.

2) Choose Case No. and Enter Here. Proceed to "Uplink & Downlink Choices" Below

HEO Orbit Geometry



CASE NO. SELECTED: 13 — 35,786.0 km Altitude — **Elevation Angle:** 5.0 ° — **Slant Range (S):** 41,126.8 km

CASE:		*R(km):*	*M(deg.):*	*altitude (km):*	*S/C off-point angle:*	*S/C rcvr. ant. temp.(K)*
1	perigee	6878.1	0	500.0	180.0 deg.	35
2		6977.6	15	599.5	165.0 deg.	35
3		7286.6	30	908.5	150.0 deg.	35
4		7838.8	45	1,460.7	135.0 deg.	35
5		8697.9	60	2,319.8	120.0 deg.	35
6		9970.3	75	3,592.2	105.0 deg.	35
7		11827.0	90	5,448.8	90.0 deg.	35
8		14533.4	105	8,155.2	75.0 deg.	35
9		18472.4	120	12,094.3	60.0 deg.	35
10		24076.0	135	17,697.8	45.0 deg.	40
11		31380.2	150	25,002.0	30.0 deg.	50
12		38775.1	165	32,396.9	15.0 deg.	90
13	apogee	42164.1	180	35,786.0	0.0 deg.	170
14		41756.6	175	35,378.4	5.0 deg.	160

← User Defined Case:

SOME KEY ORBIT & LINK PARAMETERS	
EARTH ANGULAR DIAMETER (g):	17.4 °
S/C POINTING VECTOR (a):	10.0 °
WORST CASE SQUINT ANGLE	18.7 °
RX ANTENNA POINTING LOSS	0.00 dB
TX ANTENNA POINTING LOSS	0.27 dB
GROUND RCVR Eb/No:	18.9 dB
S/C RCVR Eb/No	51.3 dB

3) If CASE No. 14 is Selected, Choose Mean Anomaly Value and S/C Rcvr Antenna Temp. and Enter Here

Geostationary Earth Orbit (GEO) - Option #3

NOTE:

Path Length to User Terminal from Spacecraft

Parameter:	*Value:*	*Unit:*	*Comment(s):*
Geostationary Altitude:	35,786.019	km	Height Above Geoid
Equatorial Radius of Earth (Re):	6,378.137	km	
Geostationary semi major axis	42,164.156	km	Accurate to 1/10 meter
Typical Path Length:	37,410.000	km	User at typical Longitude difference from satellite and at mean latitude.
Shortest Path Length:	35,786.019	km	User at same longitude as satellite and at the equator
Longest Path Length:	41,678.957	km	User at max. longitude difference from satellite and at max. latitude (0.0° User Elevation Angle).

UPLINK: ⟶ S/C ⟶ **DOWNLINK:**

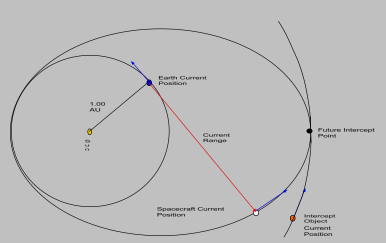
	User #1:		Comment		User #2: NOTE:		
User Latitude:	19.062	°	+ = North Latitude; - = South Latitude	User Latitude:	17.429	°	
User Longitude:	72.874	°	+ = East Longitude; - = West Longitude	User Longitude:	78.466	°	
Spacecraft Slot (Longitude):	89.500	°	Enter Slot Postion in Degrees East Longitude (NOTE: D Longitude £ 81.3°) [- = W. Long.; + = E. Long.]	S/C Slot Longitude:	89.500	°	Same as User #1 as both Users Employ the Same Spacecraft
Slant Range to User:	36488.2	km ←	The distance from the GEO satellite to the user. This Value used in Link Budget Path Loss Calculation.	Slant Range to User:	36260.4	km	
User Elevation Angle:	60.660	°	This is the Elevation Angle to the GEO spacecraft from the User (latitude and longitude) site.	User Elevation Angle:	65.926	°	
User Azimuth Angle:	137.564	°	This is the azimuth angle to the GEO spacecraft from the User (latitude and longitude) site.	User Azimuth Angle:	146.935	°	
Earth Central Angle:	25.089	°	The angle measured from Earth center between the sub-satellite point and the ground station location.	Earth Central Angle:	20.536	°	

Deep Space Mission - Option #4: Range Expressed in Astronomical Units (AU)

NOTE:

Mission Target Object: Mars — Current Range to S/C: 2.100 AU

Current Range to S/C: 3.150E+08 km



Heliocentric Transfer Mission (Example)

UPLINK & DOWNLINK Frequency Choices:

Orbit Type Selected: **LEO**

Path Loss = 22.0 + 20 log (S/l)

Slant Range for Orbit Option Selected: **1,440 km**

NOTE:

	Option:	Frequency:	Wavelength (l):		Path Loss:				
Uplink:	#1:	145.800 MHz	2.056	meters	138.9	dB	Uplink Frequency Choice:	4	145.840 MHz
	#2:	437.500 MHz	0.685	meters	148.4	dB			
	#3:	1269.900 MHz	0.236	meters	157.7	dB	Path Loss for Orbit Selected:		138.9 dB
Operator Selected Option: →	#4:	145.840 MHz	2.056	meters	138.9	dB			
Downlink:	#1:	145.800 MHz	2.056	meters	138.9	dB	Downlink Frequency Choice:	4	435.300 MHz
	#2:	437.450 MHz	0.685	meters	148.4	dB			
	#3:	2405.000 MHz	0.125	meters	163.3	dB	Path Loss for Orbit Selected:		148.4 dB
Operator Selected Option: →	#4:	435.300 MHz	0.689	meters	148.4	dB			

System Transmitters & Line Losses: NEUTRON1 2019 Feburary 22

Uplink Transmitter System (At Ground Station):

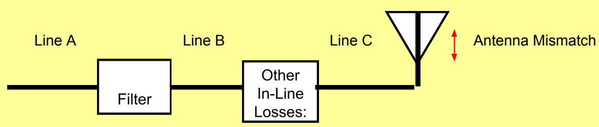
NOTE:

Block Diagram:

Transmitter Power:	100.00	Watts =	20.0	dBW =	50.00	dBm
Cable or Waveguide ("Line") Losses:						
Line A Length:					3.5	meters
Line B Length:					45.7	meters
Line C Length:					10.0	meters
Total Line Length (Line A+B+C):					59.2	meters
Cable/W. Guide Type:					Heliax 3/8	cable
Cable/W.Guide Loss/meter:	0.04 dB	At (freq.)	145.840	MHz =	2.49824	dB
Other Components in Line:						
No. of In-Line Connectors:	5	Connectors X 0.05 dB/Con.		=	0.25	dB
Filter Insertion Losses:					0.04	dB
Other In-Line Losses:	Device:	Lightning Protection			0.035	dB
Antenna Mismatch Losses:		(See "VSWR Loss Tool" W/S)			0.12	dB
Total Line Losses:					2.94	dB
Total Power Delivered to Antenna:					17.06	dBW

Downlink Transmitter System (At Spacecraft):

Block Diagram:



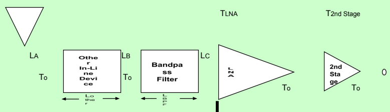
Transmitter Power:	0.4	Watts =	-3.7	dBW =	26.33	dBm
Cable or Waveguide Loss:						
Line A Length:					0	meters
Line B Length:					0	meters
Line C Length:					0.2	meters
Total Line Length (Lines A+B+C):					0.2	meters
Cable/Guide Type:					RG-316/U	cable
Cable/Guide Loss/meter:	0.47 dB	At (freq.)	435.300	MHz =	0.0944	dB
Other Components in Line:						
No. of In-Line Connectors:	2	Connectors X 0.05 dB		=	0.1	dB
Filter Insertion Losses:					0.0	dB
Other In-Line Losses:	Device:	None			0	dB
Antenna Mismatch Losses:		(See "VSWR Loss Tool" W/S)			0.510	dB
Total Line Losses:					0.70	dB
Total RF Power Delivered to Antenna:					-4.37	dBW

System Receivers and Line Losses: NEUTRON1 2019 Feburary 22

Uplink Receiver System (At Spacecraft):

NOTE:

Block Diagram:



System Noise Temperature (T_s):

$$T_s = (a)T_a + (1-a)T_o + T_{LNA} + T_{2ndStage}/G_{LNA}$$

Where:

T_a = Antenna Temperature or Sky Temperature (°K)

T_o = System Line Temperature (Physical Temperature) (°K) ° System Reference Temperature

T_{LNA}= Noise Temperature of the Low Noise Amplifier (°K)

$T_{2nd\ Stage}$ = Noise Temperature of Next Stage Amplifier or Mixer (°K)

G_{LNA} = The gain of the LNA in linear (non-dB) units NOTE:

a = Feed Line Coefficient = 10^ -((LA/10)+(LB/10)+(LC/10)+(LBPF/10)+(Lother/10))

Where:

- L_A, L_B, L_C = All Cable or Waveguide Losses (expressed in dB)
- L_{BPF} = Insertion Loss of any bandpass fiter used in front of LNA (expressed in dB)
- L_{other} = Insertion Loss of any other In-Line device in front of LNA (expressed in dB)

Cable or Waveguide "Line" Losses:

Line A Length:		0 meters
Line B Length:		0 meters
Line C Length:		0.2 meters
Cable/Guide Type:		RG-316/U cable
Cable/Guide Loss/meter:	0.5 dB at frequency	145.8 MHz
Line A Loss:	L_A =	0 dB
Line B Loss:	L_B =	0 dB
Line C Loss:	L_C =	0.0944 dB
Bandpass Filter Insertion Loss:	L_{BPF} =	0.0 dB
Insertion Loss of Other In-Line Devices:	L_{other} =	0 dB
No. of In-Line Connectors: 2	X .05 dB/Con.=	0.1 dB
Other In-Line Device Type:		None
Total In-Line Losses from Antenna to LNA:		0.1944 dB
Transmission Line Coefficient:	a =	0.9562
Antenna or "Sky" Temperature: NOTE:	T_a =	117.62 K
Spacecraft Temperature:	T_o =	280 K
LNA Temperature:	T_{LNA} =	0 K
LNA Gain: 0.0 dB	G_{LNA} =	1.0
2nd Stage Temperature:	$T_{2ndStage}$ =	2000 K
System Noise Temperature:	T_s =	2124.7 K

Noise Temperature/Noise Figure Calculator (Tool): NOTE:

$NF_{dB} = 10\ LOG_{10}[1+(T/T_o)]$

or

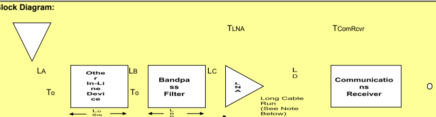
$T = T_o[10^{\wedge}(NF_{dB}/10)-1]$

T_o = 280 K

NF_{dB} =	1.0 dB	T =	72.5 K
OR			
T =	1000.0 K	NF_{dB} =	6.60 dB
Enter Data Here:		Result is Here	

Downlink Receiver System (At Ground Station):

Block Diagram:



System Noise Temperature (T_s):

$$T_s = (a)T_a + (1-a)T_o + T_{LNA} + T_{ComRcvr}/(G_{LNA}/L_D)$$

Where:

T_a =Antenna Temperature or Sky Temperature (°K)

T_o = System Line Temperature (Physical Temperature) (°K)

T_{LNA}= Noise Temperature of the Low Noise Amplifier (°K)

$T_{ComRcvr}$ = Noise Temperature of Communications Receiver Front End (°K)

G_{LNA} = The gain of the LNA in linear (non-dB) units NOTE:

a ° Feed Line Coefficient = 10^ -((LA/10)+(LB/10)+(LC/10)+(LBPF/10)+(Lother/10))

Where:

- L_A, L_B, L_C = All Cable or Waveguide Losses (expressed in dB)
- L_{BPF} = Insertion Loss of any bandpass fiter used in front of LNA (expressed in dB)
- L_{other} = Insertion Loss of any other In-Line device in front of LNA (expressed in dB)

Cable or Waveguide "Line" Losses: NOTE:

Line A Length:		5 meters	Adjusted length to quantify LMR 400 UF cable loss (IR)
Line B Length:		5 meters	
Line C Length:		1 meters	Adjusted length to quantify LMR 195 cable loss (IR)
Cable/Guide Type:		LMR 400	
Cable/Guide Loss/meter:	0.085 dB (at freq.)	435.3 MHz	
Line A Loss:	L_A =	0.425 dB	
Line B Loss:	L_B =	0.425 dB	
Line C Loss:	L_C =	0.085 dB	
Bandpass Filter Insertion Loss:	L_{BPF} =	1.5 dB	
Insertion Loss of Other In-Line Devices:	L_{other} =	0.0 dB	
No. of In-Line Connectors: 7	X 0.05 dB/con.=	0.4 dB	
Other In-Line Device Type:		none	
Total In-Line Losses from Antenna to LNA:		2.79 dB	
Transmission Line Coefficient:	a =	0.5266	
Antenna or "Sky" Temperature: NOTE:	T_a =	293 K	
Ground Station Feedline Temperature:	T_o =	290 K	
LNA Temperature:	T_{LNA} =	60 K	
LNA Gain: 20.0 dB	G_{LNA} =	100.0	
Cable/Waveguide D Length: NOTE:		45.7 meteres	
Cable/Waveguide D Type:		LMR 400	
Cable/Waveguide D Loss/meter:		0.085 dB/m	
Cable/Waveguide D Loss:		3.9 dB	
Communications Receiver Front End Temperature	$T_{ComRcvr}$ =	1000 K	
System Noise Temperature:	T_s =	376 K	

Ground Station, Antenna or Sky Noise Temperature Calculation Tool:

Galactic Noise Component:

Receiver Frequency:	437.5 MHz
Coldest Galactic Noise Temp.:	20 K
Warmest Galactic Noise Temp:	84 K

Terrestrial Noise Component:

Receiver Bandwidth:	20.0 KHz
NOTE: Estimated or Measured Noise Level:	-132.4 dBm
Noise Source Effective Temperature:	208 K
Minimum Sky Noise Temp:	228 K
Maximum Sky Noise Temp:	293 K

System Antenna Gains (Directivities): NEUTRON1 2019 Feburary 22

Uplink Antenna System:

NOTE:

Ground Station:

Uplink Frequency: 145.840 MHz — Wavelength: 2.0557 meters

Operator Selects Option 1 to 4 Here: 1 Yagi — Polarization: RHCP

OPTION:										
1	Yagi	Boom Length (l): 2.1	Optimum Elements (n): 9	per Plane (in V and in H)	Maximum Gain:	14.4	dBiC	Beamwidth:	38.1 °	Antenna Length: 4.317 meters
2	Helix	Turns (n): 10	Turn Spacing (l): 0.25	Circumference (l): 1.0	Gain:	15.7	dBiC	Beamwidth:	33.0 °	Antenna Length: 5.139 meters
3	Parabolic Reflector	Diameter: 5.4 m	Aperture Efficiency: 55%		Gain:	15.7	dBiC	Beamwidth:	26.7 °	
4	User Defined	KLM (22x22 Element) Yagi	(Example)		Gain:	18.5	dBiC	Beamwidth:	24.0 °	Antenna Length: X.XX meters

Spacecraft:

Uplink Frequency: 145.840 MHz — Wavelength: 2.0557 meters

Operator Selects Option 1 to 7 Here: 2 Dipole — Polarization: RHCP

OPTION:							
1	Monopole	Gain:	2.15	dBiL	Beamwidth:	156.2 °	No Radiation in Back Hemisphere **AND** Null on Axis ("Tip Null")
2	Dipole	Gain:	2.15	dBiL	Beamwidth:	156.2 °	Null On Axis; Both Poles
3	Canted Turnstyle	Gain:	2.0	dBiC (typical)	Beamwidth:	180 °	Circular Pol. On Axis; RHCP one pole, LHCP Opposite Pole, Linear in Equatorial Plane
4	Quadrifilar Helix Loop (l): 1/2	Gain:	4.0	dBiC	Beamwidth:	150 °	No Radiation in Back Hemisphere; Excellent Axial Ratio Performance Off-Axis
5	Patch	Gain:	6.0	dBi (L or C)	Beamwidth:	90 °	Low Radiation in Back Hemisphere; High On-Axis Gain; Can be Maded Linear or Circularly Polarized
6	Parabolic Reflector	Gain:	15.7	dBi (L or C)	Beamwidth:	26.7 °	To Be Used if a High Gain Antenna is Required on S/C. Dish Diameter: 5.4 m; Dish Aperture Efficiency: 55%
7	Other (User Defined) [Isotropic Radiator]	Gain:	0.0	dBi	Beamwidth:	360 °	Gain, Beamwidth and Roll-Off Equation To Be Provided By Link Model Operator

UPLINK ↑ DOWNLINK ↓

Downlink Antenna System:

Spacecraft:

Downlink Frequency: 435.300 MHz — Wavelength: 0.6887 meters

Operator Selects Option 1 to 5 Here: 2 Dipole — Polarization: RHCP

OPTION:							
1	Monopole	Gain:	2.15	dBiL	Beamwidth:	156.2 °	No Radiation in Back Hemisphere & Null on Axis ("Tip Null")
2	Dipole	Gain:	2.15	dBiL	Beamwidth:	156.2 °	Null On Axis; Both Poles
3	Canted Turnstyle	Gain:	2.0	dBiC (typical)	Beamwidth:	180 °	Circular Pol. On Axis; RHCP one pole, LHCP Opposite Pole, Linear in Equatorial Plane
4	Quadrifilar Helix Loop (l): 1/2	Gain:	4.0	dBiC	Beamwidth:	150 °	No Radiation in Back Hemisphere
5	Other (User Defined) Patch (Example)	Gain:	6.0	dBi (L or C)	Beamwidth:	90 °	No Radiation in Back Hemisphere
6	Parabolic Reflector	Gain:	16.6	dBi (L or C)	Beamwidth:	24.1 °	To Be Used if a High Gain Antenna is Required on S/C. Dish Diameter: 2.0 m; Dish Aperture Efficiency: 55%
7	Other (User Defined) [Isotropic Radiator]	Gain:	0.0	dBi	Beamwidth:	360 °	Gain, Beamwidth and Roll-Off Equation To Be Provided By Link Model Operator

Ground Station:

Downlink Frequency: 435.300 MHz — Wavelength: 0.6887 meters

Operator Selects Option 1 to 4 Here: 1 Yagi — Polarization: RHCP

OPTION:										
1	Yagi	Boom Length (l): 4.7	Optimum Elements (n): 15	per Plane (in V and in H)	Maximum Gain:	18.2	dBiC	Beamwidth:	24.7 °	Antenna Length: 3.237 meters
2	Helix	Turns (n): 10	Turn Spacing (l): 0.25	Circumference (l): 1.0	Gain:	15.7	dBiC	Beamwidth:	72.7 °	Antenna Length: 1.722 meters
3	Parabolic Reflector	Diameter: 2.0 m	Aperture Efficiency: 60%		Gain:	17.0	dBiC	Beamwidth:	24.1 °	
4	User Defined	KLM (22x22 Element) Yagi	(Example)		Gain:	18.5	dBiC	Beamwidth:	24.0 °	Antenna Length: X.XX meters

Look-Up Table

Optimum Yagi Antenna Performance:

Boom Length (l):	Optimum No. Elements (n):	Maximum Gain (dBi):
0.35	3	9.65
0.55	4	10.86
0.80	5	11.85
1.15	6	12.45
1.45	7	13.35
1.80	8	14.05
2.10	9	14.40
2.45	10	15.25
2.80	11	15.95
3.15	12	16.30
3.55	13	16.95
4.00	14	17.45
4.40	15	18.15
4.75	16	18.65
5.20	17	19.35
5.55	18	19.85
6.00	19	20.25
6.50	20	20.75
7.00	21	21.35
7.50	22	21.65

Data Taken from *ARRL Antenna Book*

System Antenna Pointing Losses: NEUTRON1 2019 Feburary 22

NOTE:

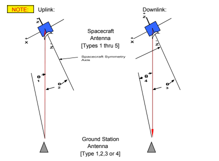
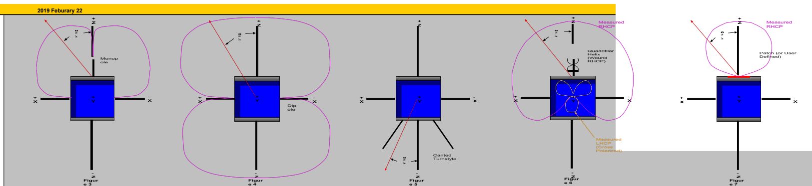
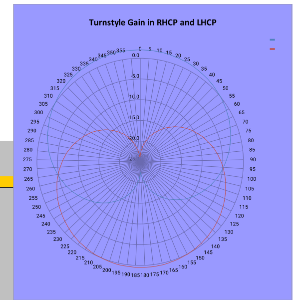


Figure 1 Figure 2





Antenna Loss Determination:

(See Also Figure 8)

Uplink Antenna System:

NOTE:

Ground Station:

Uplink Frequency: 145.840 MHz Wavelength: 2.0557 meters

This Option was Selected on the Previous Page: 1 Yagi Polarization: RHCP

1	Yagi	Maximum Gain:	14.4	dBiC	Beamwidth:	38.1 °
2	Helix	Gain:	15.7	dBiC	Beamwidth:	33.0 °
3	Parabolic Reflector	Gain:	15.7	dBiC	Beamwidth:	26.7 °
4	User Defined	Gain:	18.5	dBiC	Beamwidth:	24.0 °

Esimated Pointing Error (θ1): 12 ° **Approx. Antenna Pointing Loss:** 1.1 dB

NOTE: 50.23

Spacecraft:

Uplink Frequency: 145.840 MHz Wavelength: 2.0557 meters

This Option was Selected on the Previous Page: 7 Dipole Polarization: RHCP

						Antenna Coordinate System:		Antenna Roll-Off Calculation Formulas
1	Monopole	Gain:	2.15 dBiL	Beamwidth:	156.2 °	See Figures 1and 3	monopole	0.1 dB
2	Dipole	Gain:	2.15 dBiL	Beamwidth:	156.2 °	See Figures 1and 4	dipole	6.8 dB
3	Canted Turnstyle	Gain:	2.0 dBiC	Beamwidth:	180 °	See Figures 1, 5 & 8	canted turnstyle	4.6 dB
4	Quadrifilar Helix Loop (l): 1/2	Gain:	4.0 dBiC	Beamwidth:	150 °	See Figures 1and 6	quadrifilar helix	3.3 dB
5	Patch	Gain:	6.0 dBi (C or L)	Beamwidth:	90 °	See Figures 1and 7	patch antenna	11.2 dB
6	Parabolic Reflector [For S/C Hi Gain Option]	Gain:	15.7 dBi (C or L)	Beamwidth:	26.7 °	Dish Boresight Aligned with +Z Axis	parabolic reflector	18.6 dB
7	Other (User Defined) [Isotropic Radiator]	Gain:	0.0 dBi	Beamwidth:	360 °	Link Model Operator to Provide	user defined	0.0 dB

466.62 — Intermediate Calculation - Please Ignore This Value.

Link Model operator enter equation for functional behavior of user defined antenna here.

Angle between S/C antenna symmetry axis and vector from S/C to gnd. station (θ2): 78 ° **Approx. Antenna Pointing Loss:** 0.0 dB

UPLINK **DOWNLINK**

Downlink Antenna System:

Spacecraft:

Downlink Frequency: 435.300 MHz Wavelength: 0.6887 meters

This Option was Selected on the Previous Page: 2 Dipole Polarization: RHCP

						Antenna Coordinate System:		Antenna Roll-Off Calculation Formulas
1	Monopole	Gain:	2.15 dBiL	Beamwidth:	156.2 °	See Figures 2 and 3	monopole	4.7 dB
2	Dipole	Gain:	2.15 dBiL	Beamwidth:	156.2 °	See Figures 2 and 4	dipole	0.3 dB
3	Canted Turnstyle	Gain:	2.0 dBiC	Beamwidth:	180 °	See Figures 2, 5 & 8	canted turnstyle	0.3 dB
4	Quadrifilar Helix Loop (l): 1/2	Gain:	4.0 dBiC	Beamwidth:	150 °	See Figures 2 and 6	quadrifilar helix	0.2 dB
5	Other (User Defined) Patch (Example)	Gain:	6.0 dBi	Beamwidth:	90 °	See Figures 2 and 7	Patch (Example)	0.6 dB
6	Parabolic Reflector [For S/C Hi Gain Option]	Gain:	16.6 dBi (C or L)	Beamwidth:	24.1 °	Dish Boresight Aligned with +Z Axis	parabolic reflector	9.9 dB
7	Other (User Defined) [Isotropic Radiator]	Gain:	0.0 dBi	Beamwidth:	360 °	Link Model Operator to Provide	user defined	0.0 dB

132.26 — Intermediate Calculation - Please Ignore This Value.

Enter functional behavior of user defined antenna here.

Angle between S/C antenna symmetry axis and vector from S/C to gnd. station (θ3): 20 ° **Approx. Antenna Pointing Loss:** 0.3 dB

Ground Station:

Downlink Frequency: 435.300 MHz Wavelength: 0.6887 meters

This Option was Selected on the Previous Page: 1 Yagi Polarization: RHCP

1	Yagi	Maximum Gain:	18.2	dBiC	Beamwidth:	24.7 °
2	Helix	Gain:	15.7	dBiC	Beamwidth:	72.7 °
3	Parabolic Reflector	Gain:	17.0	dBiC	Beamwidth:	24.1 °
4	User Defined	Gain:	18.5	dBiC	Beamwidth:	24.0 °

77.35

Esimated Pointing Error (θ4): 12 ° **Approx. Antenna Pointing Loss:** 2.8 dB

System Polarization Loss and Cross Polarization Isolation: NEUTRON1 — 2019 Feburary 22

Axial Ratio ≡ 10*LOG [Power Emitted (or Received) with Antenna Aligned with Major Axis / Power Emitted (or Received) with Antenna Aligned with Minor Axis]

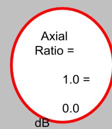
NOTE:

Power when Aligned with Minor Axis

	Circular	**Elliptical**	**Linear**
	Right Hand or Left Hand	Right Hand or Left Hand	Vertical or Horizontal

Power when Aligned with Major Axis

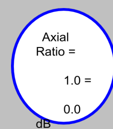
Transmit Antenna



Axial Ratio = ∞

Power when Aligned with Major Axis

Receive Antenna

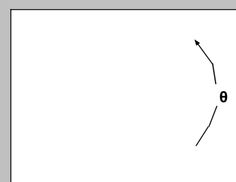


Axial Ratio = ∞

NOTE:

UPLINK: Operator selects uplink antenna characteristics in blue boxes.

Polarization Loss Calculation:		
Co-Polarization Loss:		
Axial ratio of Tx Antenna (Ant. #1) in dB =	3.50	[dB]
Axial ratio (Ant. #1) =	1.50	[ ]
Axial ratio of Rx Antenna (Ant. #2) in dB =	500.00	[dB]
Axial ratio (Ant. #2) =	000000000	[ ]
Polarization Angle θ between antennas =	90.0	[degrees]
Polarization Angle θ between antennas =	.57079632	[Radians]
Polarization Loss =	0.30876	[ ]
Polarization Loss =	5.10	[dB]
Cross Polarization Coupling/Isolation:		
Cross Pol. Power Fraction =	0.69124	
Cross Pol. Power Fraction =	-1.60	[dB]
Cross Polarization Isolation =	6.71	[dB]



Polarization Angle (θ) ≡ Angle between transmit and receive major axes.

Polarization Loss Equation:

PL = 0.5*(1+((1-r_1^2)*(1-r_2^2)*COS(2*θ)+4*r_1*r_2)/((1+r_1^2)*(1+r_2^2)))

DOWNLINK: Operator selects uplink antenna characteristics in blue boxes.

Polarization Loss Calculation:		
Co-Polarization Loss:		
Axial ratio of Tx Antenna (Ant. #1) in dB =	500.00	[dB]
Axial ratio (Ant. #1) =	000000000	[ ]
Axial ratio of Rx Antenna (Ant. #2) in dB =	1.50	[dB]
Axial ratio (Ant. #2) =	1.19	[ ]
Polarization Angle θ between antennas =	90.0	[degrees]
Polarization Angle θ between antennas =	.57079632	[Radians]
Polarization Loss =	0.41450	[ ]
Polarization Loss =	3.82	[dB]
Cross Polarization Coupling/Isolation:		
Cross Pol. Power Fraction =	0.58550	
Cross Pol. Power Fraction =	-2.32	[dB]
Cross Polarization Isolation =	6.15	[dB]

Example Calculations:

	Tx Ant. A.R. #1: (dB)	**Rx Ant. A.R. #2: (dB)**	**θ (degrees)**	**Pol. Loss (dB)**
Tx Circular,	0.0	0.0	90.0	0.00
Rx Variable:	0.0	1.0	90.0	-0.01
	0.0	2.0	90.0	-0.06
	0.0	3.0	90.0	-0.13
	0.0	6.0	90.0	-0.45
	0.0	10.0	90.0	-1.04
	0.0	30.0	90.0	-2.74
	0.0	30.0	0.0	-2.74
Tx & Rx Elliptical:	3.0	3.0	0.0	0.00
	3.0	3.0	45.0	-0.25
	3.0	3.0	90.0	-0.51
Tx & Rx Linear:	30.0	30.0	0.0	0.00
	30.0	30.0	30.0	-1.24
	30.0	30.0	45.0	-2.99
	30.0	30.0	60.0	-5.97
	30.0	30.0	90.0	-23.99
Tx Elliptical,	2.0	30.0	0.0	-1.91
Rx Linear	2.0	30.0	45.0	-2.75
	2.0	30.0	90.0	-3.79

NOTE: A linearly polarized antenna may be represented by an Axial Ratio value of 30 dB.

NOTE: This is a typical small satellite case.

NOTE: This is also a typical small satellite case.

Atmospheric and Ionospheric Losses: NEUTRON1 2019 Feburary 22

Loss due to Atmospheric Gases:		
Uplink and Downlink:		
Elevation Angle:	*Loss:*	*Unit:*
0 °	10.2	dB
2.5 °	4.6	dB
5 °	2.1	dB
10 °	1.1	dB
30 °	0.4	dB
45 °	0.3	dB
90 °	0.0	dB
Min. Elev. Angle:	10	deg.
Loss Determined:	1.1	dB

NOTE:

Link Losses Resulting from Signals Passing Through Atmospheric Gases:

Losses due to atmospheric gases (Nitrogen, Oxygen, Carbon Dioxide, Hydrogen, etc.) are nearly independent of atmospheric temperature, mean density and relative humidity at frequencies below 2 GHz. Atmospheric absorption depends strongly upon the total number of molecules distributed along the path between the spacecraft and the ground station. This, in turn, means that the losses from or to the satellite are elevation angle dependent.

The table to the left is a look-up table. The minimum elevation angle selected in the "Orbit" worksheet is matched against the closest fit from the table and the result is given at Cell [D23] and is automatically inserted into the uplink and downlink budgets.

The data used here is taken from "*Radiowave Propagation in Satellite Communications*" by Louis J. Ippolito, Jr., Van Nostrand-Reinhold, 1986, pp. 33-34, Tables 3-3a-c.

One additional interpolated value is added at 2.5° elevation angle. This was not taken from Ippolito's text.

If you are using uplink or downlink frequencies above 2 GHz, refer to the referenced text given above to determine the appropriate atmosperic losses. At millimeter wave frequencies the losses can be much higher.

Loss due to Ionosphere:			
Uplink:	Loss Determined:	0.4 dB	
Frequency:	*Unit:*	*Loss:*	*Unit:*
146	MHz	0.7	dB
438	MHz	0.4	dB
2410	MHz	0.1	dB
145.840	MHz	0.4	dB

Link Model Operator Estimate Inserted Here.

Loss due to Ionosphere:			
Downlink:	Loss Determined:	0.8 dB	
Frequency:	*Unit:*	*Loss:*	*Unit:*
146	MHz	0.7	dB
438	MHz	0.4	dB
2410	MHz	0.1	dB
435.300	MHz	0.8	dB

Link Model Operator Estimate Inserted Here.
If the "Link Model Operator" has selected a user option for the frequency, then an estimate of the ionospheric losses must be provided by the operator.

Link Losses Resulting from Signals Passing Through the Ionosphere:

Radio waves passing through the ionosphere at VHF, UHF and Microwave frequencies are influenced far less by this layer of ionized particles than at frequencies in the HF, MF and LF portions of the radio spectrum. While there is certainly some correlation between the elevation angle to a satellite and the signal absorption or scintillation experienced, this dependency is nearly masked out by the time variability of effects.

There is, however, a frequency depencency that can be quantified, on average. As transmitter frequencies go below 100 MHz there are times when the attenuation can increase to as much as tens of dB, especially at low elevation angles. The ionosphere certainly limits the lowest frequency at which satellite communications is feasible. Below 20 MHz, during solar maximum space signals are usually fully absorbed or reflected by the layers of the ionosphere (D, E, F_1 and F_2).

The values provided in this table are approximate mean values for low earth station elevation angles. It is proposed that these values can be conservatively used in satellite link analyses. The higher order statistics of these loss parameters would be interesting to review, however, this effort is more than is necessary for the development of an effective link budget.

The losses determined here for the uplink and downlink are based on the operator-selected frequency choice made in the "Orbit" worksheet. If the "User Defined" option is selected by the link model operator, then the operator must estimate the appropriate ionospheric loss value and manually insert it in either Cell [D34] or Cell [D47] accordingly.

Proceed to the "Modulation-Demodulation Method" W/S.

Modulation/Demodulation Method: **NEUTRON1** **2019 Feburary 22**

NOTE:			Select Here:	Choice Made:	Result:
UPLINK:	**Modulation, Coding & BER Option:**		**1**	AFSK/FM	
Command Link					
Option:	Modulation Type:	Coding:	Bit Error Rate Spec:	Required Eb/No (dB):	
1	AFSK/FM	None	1.00E-04	21.0	
2	AFSK/FM	None	1.00E-05	23.2	
3	G3RUH FSK	None	1.00E-04	16.7	
4	G3RUH FSK	None	1.00E-05	18.0	
5	Non-Coherent FSK	None	1.00E-04	13.4	
6	Non-Coherent FSK	None	1.00E-05	13.8	
7	Coherent FSK	None	1.00E-04	10.5	
8	Coherent FSK	None	1.00E-05	11.9	
9	GMSK	None	1.00E-04	8.4	
10	GMSK	None	1.00E-05	9.6	
11	BPSK	None	1.00E-05	9.6	
12	BPSK	None	1.00E-06	10.5	
13	QPSK	None	1.00E-05	9.6	
14	QPSK	None	1.00E-06	10.5	
15	BPSK	Convolutional R=1/2, K=7	1.00E-06	4.8	
16	BPSK	Conv. R=1/2,K=7 & R.S. (255,223)	1.00E-06	2.5	
17	BPSK	Conv. R=1/6,K=15 & R.S. (255,223)	1.00E-07	0.8	
18	User Defined	None	1.00E-05	9.6	
		Operator Estimate of Implementation Loss			
NOTE:		**Implementation Loss Estimate:**	**1.0**	dB	

Eb/No: Threshold
22.0 dB

UPLINK: ↓ **DOWNLINK:** ↓

			Select Here:	Choice Made:	Result:
DOWNLINK:	**Modulation, Coding & BER Option:**		**10**	GMSK	
Telemetry Link:					
Option:	Modulation Type:	Coding:	Bit Error Rate Spec:	Required Eb/No (dB):	
1	AFSK/FM	None	1.00E-04	21.0	
2	AFSK/FM	None	1.00E-05	23.2	
3	G3RUH FSK	None	1.00E-04	16.7	
4	G3RUH FSK	None	1.00E-05	18.0	
5	Non-Coherent FSK	None	1.00E-04	13.4	
6	Non-Coherent FSK	None	1.00E-05	13.8	
7	Coherent FSK	None	1.00E-04	10.5	
8	Coherent FSK	None	1.00E-05	11.9	
9	GMSK	None	1.00E-04	8.4	
10	GMSK	None	1.00E-05	9.6	
11	BPSK	None	1.00E-05	9.6	
12	BPSK	None	1.00E-06	10.5	
13	QPSK	None	1.00E-05	9.6	
14	QPSK	None	1.00E-06	10.5	
15	BPSK	Convolutional R=1/2, K=7	1.00E-06	4.8	
16	BPSK	Conv. R=1/2,K=7 & R.S. (255,223)	1.00E-06	2.5	
17	BPSK	Conv. R=1/6,K=15 & R.S. (255,223)	1.00E-07	0.8	
18	BPSK	Turbo Code (Parallel w. Interleaver)	1.00E-06	0.75	
19	User Defined	None	1.00E-05	9.6	
		Operator Estimate of Implementation Loss			
		Implementation Loss Estimate:	**0.0**	dB	
NOTE:					

Eb/No: Threshold
9.6 dB

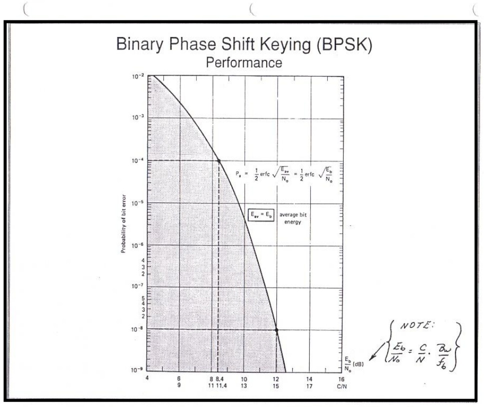


Figure 1

NEUTRON1	NOTE:		NEUTRON1	Date Data Last Modified:
Uplink Command Budget:			**Version: 2.5.5**	**2019 Feburary 22**

Parameter:	*Value:*	*Units:*	*Comments:*
Ground Station:			
Ground Station Transmitter Power Output:	100.0	watts	This value is transferred from "Transmitters" W/S, Cell [E15]. — NOTE: Click " + " above column J to restore comment column.
In dBW:	20.0	dBW	Transmitter power expressed in dB above one watt
In dBm:	50.0	dBm	Transmitter power expressed in dB above one milliwatt
Ground Stn. Total Transmission Line Losses:	2.9	dB	This value is transferred from "Transmitters" W/S, Cell [I33]
Antenna Gain:	14.4	dBi	This value is selected at "Antenna Gain" W/S, Cell [E11]
Ground Station EIRP:	31.5	dBW	Ground Station Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]
Uplink Path:			
Ground Station Antenna Pointing Loss:	1.1	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and transferred from Cell [K43]
Gnd-to-S/C Antenna Polarization Losses:	5.1	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F40].
Path Loss:	138.9	dB	Lp = 22 + 20LOG(D/l); Transferred from "Frequency" W/S
Atmospheric Losses:	1.1	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]
Ionospheric Losses:	0.4	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D47:D50]
Rain Losses:	0.0	dB	This value should be estimated by the link model operator and place into Cell [B18]
Isotropic Signal Level at Spacecraft:	-115.2	dBW	This is the signal level received in space in the vacinity of the spacecraft using an omnidirectional antenna.
Spacecraft (Eb/No Method):			
------- Eb/No Method -------			
Spacecraft Antenna Pointing Loss:	0.0	dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K63]
Spacecraft Antenna Gain:	2.2	dBi	This value is selected at "Antenna Gain" W/S, Cell [E24]
Spacecraft Total Transmission Line Losses:	0.2	dB	This value is transferred from the "Receivers" W/S, Cell [J52]
Spacecraft Effective Noise Temperature:	2125	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J67]
Spacecraft Figure of Merrit (G/T):	-31.3	dB/K	G/T = Ga-Ltl-10log(Ts). This is the uptimate measure of the receiver's performance.
S/C Signal-to-Noise Power Density (S/No):	82.1	dBHz	Boltzman's Constant: -228.6 dBW/K/Hz
System Desired Data Rate:	1200	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.
In dBHz:	30.8	dBHz	This is simply = 10log(R); R= data rate
Command System Eb/No:	51.3	dB	
Demodulation Method Seleted:	AFSK/FM		Values selected in "Modulation-Demodulation W/S, Cell [E3]
Forward Error Correction Coding Used:	None		Value selected in "Modulation-Demodulation" W/S, also Cell [E3]
System Allowed or Specified Bit-Error-Rate:	1.0E-04		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E6:E23]
Demodulator Implementation Loss:	1.0	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E25]
Telemetry System Required Eb/No:	21.0	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F6:F23]
Eb/No Threshold:	22.0	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]
System Link Margin:	**29.3**	dB	

Spacecraft Alternative Signal Analysis Method (SNR Computation): ← NOTE:			
---------- SNR Method ------------			
Spacecraft Antenna Pointing Loss:	0.0	dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K63]
Spacecraft Antenna Gain:	2.2	dBi	This value is selected at "Antenna Gain" W/S, Cell [E24]
Spacecraft Total Transmission Line Losses:	0.2	dB	This value is transferred from the "Receivers" W/S, Cell [J52]
Spacecraft Effective Noise Temperature:	2125	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J67]
Spacecraft Figure of Merrit (G/T):	-31.3	dB/K	G/T = Ga-Ltl-10log(Ts). This is the ultimate measure of the receiver's performance.
Signal Power at Spacecraft LNA Input:	-113.2	dBW	Ps = Piso+Ga-Lpl-Ltl; This is the signal power that has arrived at the ground station receiver.
Spacecraft Receiver Bandwidth:	10,000	Hz	Signal Spectrum Must Pass Through This Data Filter. NOTE:
Spacecraft Receiver Noise Power (Pn = kTB)	-155.3	dBW	Pn = K + 10log(Ts) + 10log(B). This is the total noise power arriving at the ground station receiver.
Signal-to-Noise Power Ratio at G.S. Rcvr:	42.1	dB	Ps/Pn = Ps(in dBW) - Pn(in dBW)
Analog or Digital System Required S/N:	14.4	dB	If system is digital, use values from "Modulation-Demodulation" W/S. If analog, use appropriate value from text book.
System Link Margin	**27.7**	dB	

NEUTRON1 NOTE: **NEUTRON1** **Date Data Last Modified:**

Downlink Telemetry Budget:

Version: 2.5.5 **2019 Feburary 22**

NOTE: Click " + " above column K to restore comment column.

Parameter:	*Value:*	*Units:*	*Comments:*
Spacecraft:			
Spacecraft Transmitter Power Output:	0.4	watts	This value is transferred from "Transmitters" W/S, Cell [E50]
In dBW:	-3.7	dBW	Transmitter power expressed in dB above one watt
In dBm:	26.3	dBm	Transmitter power expressed in dB above one milliwatt
Spacecraft Total Transmission Line Losses:	0.7	dB	This value is transferred from "Transmitters" W/S, Cell [I68]
Spacecraft Antenna Gain:	2.2	dBi	This value is selected at "Antenna Gain" W/S, Cell [E41]
Spacecraft EIRP:	-2.2	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]
Downlink Path:			
Spacecraft Antenna Pointing Loss:	0.3	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and trasferred from Cell [K85]
S/C-to-Ground Antenna Polarization Loss:	3.8	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].
Path Loss:	148.4	dB	Lp = 22 + 20LOG(D/l); Transferred from "Frequency" W/S
Atmospheric Loss:	1.1	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]
Ionospheric Loss:	0.8	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D47:D50]
Rain Loss:	0.0	dB	This value should be estimated by the link model operator and place into Cell [B18]
Isotropic Signal Level at Ground Station:	-156.6	dBW	This is the signal level received at the Earth in the vacinity of the ground station using an omnidirectional antenna.
Ground Station (EbNo Method):			
------- Eb/No Method -------			
Ground Station Antenna Pointing Loss:	2.8	dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K102]
Ground Station Antenna Gain:	18.2	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]
Ground Station Total Transmission Line Losses:	2.8	dB	This value is transferred from the "Receivers" W/S, Cell [J123]
Ground Station Effective Noise Temperature:	376	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]
Ground Station Figure of Merrit (G/T):	-10.4	dB/K	G/T = G_a-L_{tl}-10log(T_s). This is the uptimate measure of the receiver's performance.
G.S. Signal-to-Noise Power Density (S/No):	58.8	dBHz	Boltzman's Constant: -228.6 dBW/K/Hz
System Desired Data Rate:	9600	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.
In dBHz:	39.8	dBHz	This is simply = 10log(R); R= data rate
Telemetry System Eb/No for the Downlink:	18.9	dB	
Demodulation Method Seleted:	GMSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]
Forward Error Correction Coding Used:	None		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]
System Allowed or Specified Bit-Error-Rate:	1.0E-05		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]
Demodulator Implementation Loss:	0.0	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E52]
Telemetry System Required Eb/No:	9.6	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]
Eb/No Threshold:	9.6	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]
System Link Margin:	**9.3**	dB	
Ground Station Alternative Signal Analysis Method (SNR Computation):			
---------- SNR Method ------------			
Ground Station Antenna Pointing Loss:	2.8	dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K102]
Ground Station Antenna Gain:	18.2	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]
Ground Station Total Transmission Line Losses:	2.8	dB	This value is transferred from the "Receivers" W/S, Cell [J123]
Ground Station Effective Noise Temperature:	376	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]
Ground Station Figure of Merrit (G/T):	-10.4	dB/K	G/T = G_a-L_{tl}-10log(T_s). This is the ultimate measure of the receiver's performance.
Signal Power at Ground Station LNA Input:	-144.1	dBW	P_s = P_{iso}+G_a-L_{pl}-L_{tl}; This is the signal power that has arrived at the ground station receiver.
Ground Station Receiver Bandwidth (B):	15,000	Hz	Signal Spectrum Must Pass Through This Data Filter **NOTE:**
G.S. Receiver Noise Power (Pn = kTB)	-161.1	dBW	Pn = K + 10log(Ts) + 10log(B). This is the total noise power arriving at the ground station receiver.
Signal-to-Noise Power Ratio at G.S. Rcvr:	17.0	dB	Ps/Pn = Ps(in dBW) - Pn(in dBW)
Analog or Digital System Required S/N:	9.6	dB	If system is digital, use values from "Modulation-Demodulation" W/S. If analog, use appropriate value from text book.
System Link Margin	**7.4**	dB	

System Performance Summary: NEUTRON1

2019 Feburary 22

COMMAND — UPLINK SYSTEM:

Frequency: 145.84 MHz

		Link Margin	
Eb/No Method:	Eb/No = 51.3 dB	29.3 dB	LINK CLOSES
S/N Method:	S/N = 42.1 dB	27.7 dB	LINK CLOSES

NOTE:

R = 1200 bps

S/C

Data FEC Decoder — F.E.C. Decoder Type: None

Data Demodulator — Spec. B.E.R.: 1.00E-04; Demodulator Type: AFSK/FM; Eb/No Threshold: 22.0 dB

Data Bandpass Filter — BRbpf = 10000 Hz (Used Only in S/N Calc.)

G/T = -31.3 dB/K

Tsys = 2125 K

2nd Amplifier — T2nd Amp = 2000 K

GLNA = 0.0 dB

TLNA = 0 K

Ltotal line = 0.19 dB

Line A — LA = 0.00 dB

LRbpf = 0.0 dB

Line B — LB = 0.00 dB

LTother = 0.0 dB; None

Line C — LC= 0.09 dB

Receive Antenna (Dipole)

GR = 2.2 dBi; Polarization: RHCP

RADIO LINK

Lp = 138.9 dB

Total Link Losses: 146.7 dB

EIRPgs = 31.5 dBW

Transmit Antenna (Yagi)

GT = 14.4 dBi; Polarization: RHCP

Ground Station

Ltotal line = 2.94 dB

Line C — LC = 0.422 dB

LTother = 0.0 dBi; Lightning Protection

Line B — LB = 1.929 dB

LTbpf = 0.0 dB

Line A — LA = 0.148 dB

HPA — PTx = 100.0 watts

Modulation Method: AFSK/FM

F.E.C. Encoder Type: None

R = 1200 bps

TELEMETRY — DOWNLINK SYSTEM:

Frequency: 435.30 MHz

R = 9600 bps

S/C

Transmitter Exciter/Modulator/FEC Encoder — Modulation Method: GMSK; F.E.C. Encoder Type: None

HPA — ηTx = 40.0%

Tx DC Pwr: 1.1 watts

Tx Dissipation: 0.6 watts

PTx = 0.4 watts

Line A — LA = 0.0 dB

LTXbpf = 0.0 dB

Line B — LB = 0.0 dB

LTother = 0.0 dB; None

Line C — LC = 0.1 dB

Ltotal line = 0.7 dB

Transmit Antenna (Dipole)

GT = 2.2 dBi; Polarization: RHCP

EIRPS/C = -2.2 dBW

RADIO LINK

Total Link Losses: 157.2 dB

LP = 148.4 dB

Receive Antenna (Yagi)

GR = 18.2 dBi; Polarization: RHCP

Ground Station

Line C — LC = 0.09 dB

LRother = 0.0 dB; none

Line B — LB = 0.43 dB

LRbpf = 1.5 dB

Line A — LA = 0.4 dB

Ltotal = 2.8 dB

TLNA = 60 K

GLNA = 20.0 dB

2nd Amp. — T2nd amp = 1000 K

Downconverters Mixers IF Amplification

Data Bandpass Filter — BRbpf = 15000 Hz (Used only in S/N Calc.)

Data Demodulator — Spec. B.E.R.: 1.00E-05; Demodulator Type: GMSK; Eb/No Threshold: 9.6 dB

Data FEC Decoder — F.E.C. Decoder Type: None

R = 9600 Hz

		Link Margin	
Eb/No Method:	Eb/No = 18.9 dB	9.3 dB	LINK CLOSES
S/N Method:	S/N = 17.0 dB	7.4 dB	LINK CLOSES

Commonly Used Spacecraft Antenna Radiation Patterns

Spacecraft Antennas

NOTE:

Monopole:	S/C Angle wrt Symmetry Axis (θ)°:	Antenna Gain (dBi):
	0	-156.98
	5	-9.45
	10	-2.45
	15	-0.72
	20	0.46
	25	1.41
	30	2.14
	35	2.74
	40	3.23
	45	3.64
	50	3.99
	55	4.28
	60	4.53
	65	4.72
	70	4.88
	75	5.00
	80	5.08
	85	5.13
	90	5.15
	92.5	0.00
	95	-20.00
	97.5	-60.00
	100	-160.00
	110	No Signal

MONOPOLE ELEVATION PATTERN

Peak Gain: 5.15 dBi

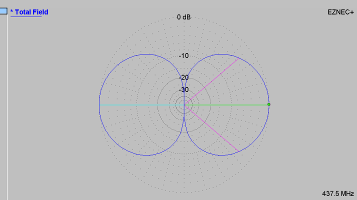
Beamwidth: 38.6 degrees (-3dB gain loss)

Peak Gain at: 0.0 degrees Elevation

Outer Ring: 5.15 dBi (Add this value to 0.0 dB)

Azimuth Cut: 0.0 degrees

Dipole:	S/C Angle wrt Symmetry Axis (θ)°:	Antenna Gain (dBi):
	0	2.15
	10	2.08
	20	1.88
	30	1.53
	40	0.99
	50	0.23
	60	-0.86
	70	-2.51
	80	-5.45
	85	-8.45
	87.5	-11.45
	90	-40.00
	92.5	-11.45
	95	-8.45
	100	-5.45
	110	-2.51
	120	-0.86
	130	0.23
	140	0.99
	150	1.53
	160	1.88
	170	2.08
	180	2.15
	190	2.08
	200	1.88
	210	1.53
	220	0.99
	230	0.23
	240	-0.86
	250	-2.51
	260	-5.45
	265	-8.45
	267.5	-11.45
	270	-40.00
	272.5	-11.45
	275	-8.45
	280	-5.45
	290	-2.51
	300	-0.86
	310	0.23
	320	0.99
	330	1.53
	340	1.88
	350	2.08
	360	2.15



DIPOLE ELEVATION PATTERN

Peak Gain: 2.15 dBi

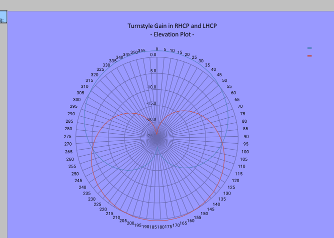
Beamwidth: 78.6 degrees (-3dB gain loss)

Peak Gain at: 0.0 degrees Elevation

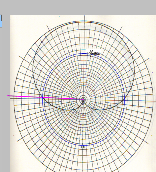
Outer Ring: 2.15 dBi (Add this value to 0.0 dB)

Azimuth Cut: 0.0 degrees

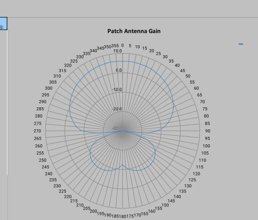
		RHCP	LHCP
Turnstyle: (Or Canted Turnstyle)	S/C Angle wrt Symmetry Axis (θ)°:	Antenna Gain (dBi):	Antenna Gain (dBi):
	0	2.0	-23.8
	5	2.0	-22.5
	10	1.9	-21.2
	15	1.8	-19.9
	20	1.7	-18.7
	25	1.5	-17.5
	30	1.3	-16.4
	35	1.1	-15.3
	40	0.8	-14.2
	45	0.5	-13.2
	50	0.1	-12.2
	55	-0.3	-11.2
	60	-0.7	-10.3
	65	-1.2	-9.4
	70	-1.7	-8.6
	75	-2.2	-7.8
	80	-2.8	-7.0
	85	-3.4	-6.3
	90	-4.1	-5.6
	95	-4.8	-4.9
	100	-5.5	-4.3
	105	-6.3	-3.7
	110	-7.1	-3.2
	115	-7.9	-2.7
	120	-8.8	-2.2
	125	-9.7	-1.8
	130	-10.7	-1.4
	135	-11.7	-1.0
	140	-12.7	-0.7
	145	-13.8	-0.4
	150	-14.9	-0.2
	155	-16.0	0.0
	160	-17.2	0.2
	165	-18.4	0.3
	170	-19.7	0.4
	175	-21.0	0.48
	180	-22.3	0.5
	185	-21.0	0.48
	190	-19.7	0.43
	195	-18.4	0.33
	200	-17.2	0.20
	205	-16.0	0.03
	210	-14.9	-0.18
	215	-13.8	-0.42
	220	-12.7	-0.70
	225	-11.7	-1.02
	230	-10.7	-1.38
	235	-9.7	-1.77
	240	-8.8	-2.20
	245	-7.9	-2.67
	250	-7.1	-3.18
	255	-6.3	-3.72
	260	-5.5	-4.30
	265	-4.8	-4.92
	270	-4.1	-5.58
	275	-3.4	-6.27
	280	-2.8	-7.00
	285	-2.2	-7.77
	290	-1.7	-8.58
	295	-1.2	-9.42
	300	-0.7	-10.30
	305	-0.3	-11.22
	310	0.1	-12.18
	315	0.5	-13.17
	320	0.8	-14.20
	325	1.1	-15.27
	330	1.3	-16.38
	335	1.5	-17.52
	340	1.7	-18.70
	345	1.8	-19.92
	350	1.9	-21.18
	355	2.0	-22.47
	360	2.0	-23.80



		RHCP	LHCP
Quadrifilar:	S/C Đ wrt Symmetry Axis (θ)°:	Antenna Gain (dBi):	Antenna Gain (dBi):
	0	4.0	
	5	4.0	
	10	4.0	
	15	3.9	
	20	3.8	
	25	3.7	
	30	3.5	
	35	3.4	
	40	3.2	
	45	3.0	
	50	2.7	
	55	2.4	
	60	2.1	
	65	1.8	
	70	1.4	
	75	1.0	
	80	0.5	
	85	0.0	
	90	-0.5	
	95	-1.1	
	100	-1.8	
	105	-2.5	
	110	-3.2	
	115	-4.1	
	120	-5.0	
	125	-6.1	
	130	-7.2	
	135	-8.5	
	140	-10.0	
	145	-11.7	
	150	-13.6	
	155	-15.9	
	160	-18.8	
	165	-22.5	
	170	-27.8	
	175	-36.8	
	180	-160.0	



		RHCP	LHCP
Patch:	S/C Angle w.r.t.Symmetry Axis (θ)	Antenna Gain (dBi):	Antenna Gain (dBi):
	0	6.0	
	5	6.0	
	10	5.9	
	15	5.7	
	20	5.4	
	25	5.1	
	30	4.7	
	35	4.2	
	40	3.7	
	45	3.0	
	50	2.2	
	55	1.3	
	60	0.3	
	65	-0.9	
	70	-2.3	
	75	-4.0	
	80	-6.0	
	85	-8.6	
	90	-12.0	
	95	-17.3	
	100	-30.2	
	105	-23.7	
	110	-16.4	
	115	-12.9	
	120	-10.7	
	125	-9.3	
	130	-8.4	
	135	-7.7	
	140	-7.4	
	145	-7.3	
	150	-7.4	
	155	-7.6	
	160	-8.1	
	165	-8.8	
	170	-9.8	
	175	-11.0	
	180	-12.6	
	185	-11.0	
	190	-9.8	
	195	-8.8	
	200	-8.1	
	205	-7.6	
	210	-7.4	
	215	-7.3	
	220	-7.4	
	225	-7.7	
	230	-8.4	
	235	-9.3	
	240	-10.7	
	245	-12.9	
	250	-16.4	
	255	-23.7	
	260	-30.2	
	265	-17.3	
	270	-8.6	
	275	-6.0	
	280	-4.0	
	285	-2.3	
	290	-0.9	
	295	0.3	
	300	1.3	
	305	2.2	
	310	3.0	
	315	3.7	
	320	4.2	
	325	4.7	
	330	5.1	
	335	5.4	
	340	5.7	
	345	5.9	
	350	6.0	
	355	6.0	



"Design a Dish"

Antenna Beam Roll-Off Tool

Beam Roll-Off & Sidelobe Positions Based on Sin² (θ)/ θ² Formulation

J. A. King 2019 Feburary 22

Frequency:	2.4	GHz
Antenna Dia.:	2.4384	Meters
Aperture Efficiency:	55	%

Peak Gain:	33.1 dBi	
Half Power (P/2) Beamwidth:	3.588	°
Wavelength:	0.125	m
Dish Diameter in Wavelengths	19.5	λ

(See Plot at Next Worksheet)

=2q (Beamwidth@ -3dB Roll-Off)

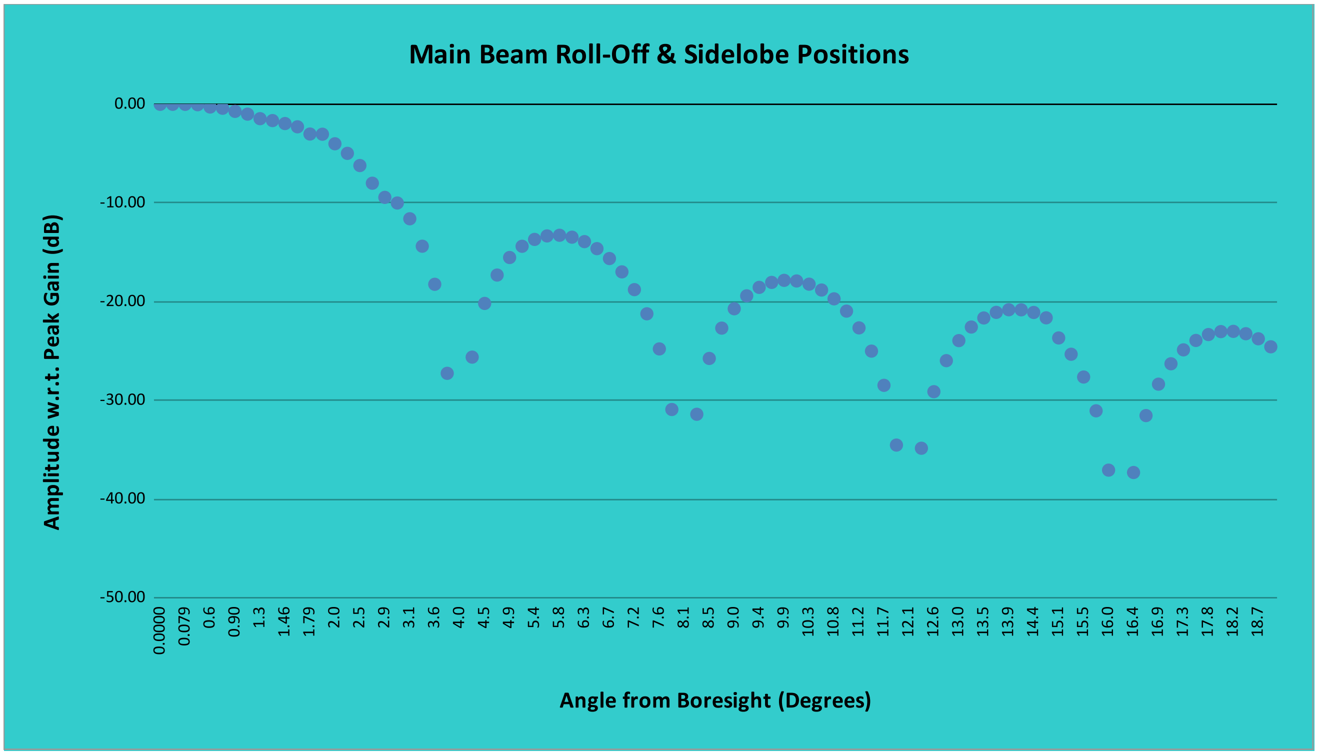
Dish Size?

OK

1.79

NOTE: NOTE: Do not modify or use cells to left of table.

Pwr (q) w.r.t. Peak Gain:		q (degrees):	
0.00	dB	0.0000	*Main Lobe*
-0.000004	dB	0.002	
-0.01	dB	0.079	
-0.04	dB	0.225	
-0.3	dB	0.6	
-0.4	dB	0.7	
-0.7	dB	0.90	
-1.00	dB	1.06	
-1.5	dB	1.3	
-1.6	dB	1.3	
-2.0	dB	1.46	
-2.3	dB	1.6	
-3.01	dB	1.79	*(Half Power B.W.)/2*
-3.03	dB	1.8	
-4.00	dB	2.0	
-5.0	dB	2.25	
-6.2	dB	2.5	
-8.0	dB	2.7	
-9.4	dB	2.9	
-10.00	dB	2.99	
-11.6	dB	3.1	
-14.4	dB	3.4	
-18.2	dB	3.6	
-27.3	dB	3.880	
-328.2	dB	4.0	First Null
-25.6	dB	4.3	
-20.2	dB	4.5	
-17.3	dB	4.7	
-15.5	dB	4.9	
-14.4	dB	5.2	
-13.7	dB	5.4	
-13.3	dB	5.6	*First Sidelobe*
-13.3	dB	5.8	
-13.5	dB	6.1	
-13.9	dB	6.3	
-14.6	dB	6.5	
-15.6	dB	6.7	
-17.0	dB	7.0	
-18.8	dB	7.2	
-21.2	dB	7.4	
-24.8	dB	7.6	
-30.9	dB	7.9	
-328.2	dB	8.1	*2nd Null*
-31.4	dB	8.3	
-25.8	dB	8.5	
-22.7	dB	8.8	
-20.7	dB	9.0	
-19.4	dB	9.2	
-18.6	dB	9.4	
-18.0	dB	9.7	
-17.8	dB	9.9	*2nd Sidelobe*
-17.9	dB	10.1	
-18.2	dB	10.3	
-18.8	dB	10.6	
-19.7	dB	10.8	
-21.0	dB	11.0	
-22.7	dB	11.2	
-25.0	dB	11.5	
-28.5	dB	11.7	
-34.5	dB	11.9	
-328.2	dB	12.1	*3rd Null*
-34.9	dB	12.4	
-29.1	dB	12.6	
-26.0	dB	12.8	
-23.9	dB	13.0	
-22.6	dB	13.3	
-21.6	dB	13.5	
-21.1	dB	13.7	
-20.8	dB	13.9	*3rd Sidelobe*
-20.8	dB	14.2	
-21.1	dB	14.4	
-21.6	dB	14.6	
-23.7	dB	15.1	
-25.3	dB	15.3	
-27.6	dB	15.5	
-31.1	dB	15.7	
-37.1	dB	16.0	
-328.2	dB	16.2	*4th Null*
-37.3	dB	16.4	
-31.5	dB	16.6	
-28.4	dB	16.9	
-26.3	dB	17.1	
-24.9	dB	17.3	
-23.9	dB	17.5	
-23.3	dB	17.8	
-23.0	dB	18.0	
-23.0	dB	18.2	*4th Sidelobe*
-23.2	dB	18.4	
-23.8	dB	18.7	
-24.6	dB	18.9	



Main Beam Roll-Off & Sidelobe Positions
Amplitude w.r.t. Peak Gain (dB)
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
0.0000
0.079
0.6
0.90
1.3
1.46
1.79
2.0
2.5
2.9
3.1
3.6
4.0
4.5
4.9
5.4
5.8
6.3
6.7
7.2
7.6
8.1
8.5
9.0
9.4
9.9
10.3
10.8
11.2
11.7
12.1
12.6
13.0
13.5
13.9
14.4
15.1
15.5
16.0
16.4
16.9
17.3
17.8
18.2
18.7
Angle from Boresight (Degrees)

Transmission Line Loss Tools and Tables:

NOTE:

Ground Station Systems:

Best Internet Cable Loss Calculator: http://www.ocarc.ca/coax.htm

2nd Best Internet Cable Loss Calculator: http://www.timesmicrowave.com/cgi-bin/calculate.pl

Coax Cable Loss Tables:
http://www.radio-ware.com/products/techinfo/coax.loss.htm
http://www.meteorscatter.net/cable.htm

Wave Guide Loss Table: http://www.advancedmicrowave.com/products/product_frame.htm

Wave Guide Primer: http://www.microwaves101.com/encyclopedia/waveguide.cfm#frequency

Spacecraft Systems:

RG-188 A/U: A PTFE (Teflon)-wrapped "clean" cable for general purpose spacecraft transmission lines. Losses are quite high per unit length as the cable diameter is only 0.098" (2.49 mm). Still, the losses are acceptable for short cable runs. The shield is silver plated copper (19 strands, each #33AWG). Typically used with SMA or SMC connectors. This is the most commonly used cable for short coax runs in very small spacecraft but, connector installation is moderately difficult.

Band:	*Frequency:*	Attenuation (dB/100 m):		*Attenuation (dB/m):*	
1	10 MHz	12.0	dB/100m	0.12	dB/m
2	30 MHz	17.0	dB/100m	0.17	dB/m
3	50 MHz	-	dB/100m	-	dB/m
4	100 MHz	28.0	dB/100m	0.28	dB/m
5	145 MHz	32.0	dB/100m	0.32	dB/m
6	200 MHz	40.0	dB/100m	0.4	dB/m
7	400 MHz	-	dB/100m	-	dB/m
8	435 MHz	58.0	dB/100m	0.58	dB/m
9	500 MHz	68.0	dB/100m	0.68	dB/m
10	1270 MHz	113.0	dB/100m	1.13	dB/m
11	2400 MHz	165.0	dB/100m	1.65	dB/m
12	3300 MHz	268.0	dB/100m	2.68	dB/m
13	5000 MHz	-	dB/100m	-	dB/m

Band: 8
Frequency: 435 MHz
Cable Length: 0.25 m
Cable Loss: 0.15 dB
NOTE:
Data courtesy K1TTT, W3LPL,PE1OYF, DJ5RH

RG-142 A/U: An FEP (Teflon) solid covered "clean" cable for general purpose spacecraft transmission lines. Losses are moderate per unit length as the cable diameter is 0.195" (4.95 mm). The losses are quite acceptable even for longer S/C cable runs. The cable is double shielded with two silver coated copper braids. The center conductor is solid copper AWG #18. Typically used with SMA or even TNC connectors. Connector installation is moderately difficult.

Band:	*Frequency:*	Attenuation (dB/100 m):		*Attenuation (dB/m):*	
1	10 MHz	7.0	dB/100m	0.07	dB/m
2	30 MHz	9.0	dB/100m	0.09	dB/m
3	50 MHz	-	dB/100m	-	dB/m
4	100 MHz	14.0	dB/100m	0.14	dB/m
5	145 MHz	15.0	dB/100m	0.15	dB/m
6	200 MHz	20.0	dB/100m	0.2	dB/m
7	400 MHz	28.0	dB/100m	0.28	dB/m
8	435 MHz	30.0	dB/100m	0.3	dB/m
9	500 MHz	35.0	dB/100m	0.35	dB/m
10	1270 MHz	49.0	dB/100m	0.49	dB/m
11	2400 MHz	72.0	dB/100m	0.72	dB/m
12	3300 MHz	95.0	dB/100m	0.95	dB/m
13	5000 MHz	128.0	dB/100m	1.28	dB/m

Band: 5
Frequency: 145 MHz
Cable Length: 0.75 m
Cable Loss: 0.11 dB
NOTE:
Data courtesy K1TTT, W3LPL, PE1OYF, DJ5RH

RG-303 /U: A PTFE (Teflon) solid covered "clean" cable for ruggedized spacecraft transmission line applications. Losses are moderate per unit length as the cable diameter is 0.170" (4.32 mm). The losses are quite acceptable even for longer S/C cable runs. The cable is single shielded with a silver coated copper braid. The center conductor is silver over copper over steel 0.039" (1 mm) dia. Typically used with SMA or even TNC connectors. This is a very rugged cable type.

Band:	*Frequency:*	Attenuation (dB/100 m):		*Attenuation (dB/m):*	
1	10 MHz	9.3	dB/100m	0.0931	dB/m
2	30 MHz	12.0	dB/100m	0.12	dB/m
3	50 MHz	-	dB/100m	-	dB/m
4	100 MHz	18.6	dB/100m	0.186	dB/m
5	145 MHz	20.0	dB/100m	0.1995	dB/m
6	200 MHz	26.6	dB/100m	0.266	dB/m
7	400 MHz	37.2	dB/100m	0.3724	dB/m
8	435 MHz	40.0	dB/100m	0.4	dB/m
9	500 MHz	46.6	dB/100m	0.4655	dB/m
10	1270 MHz	65.2	dB/100m	0.652	dB/m
11	2400 MHz	95.8	dB/100m	0.9575	dB/m
12	3300 MHz	126.4	dB/100m	1.264	dB/m
13	5000 MHz	170.2	dB/100m	1.702	dB/m

Band: 11
Frequency: 2400 MHz
Cable Length: 0.50 m
Cable Loss: 0.48 dB
NOTE:
Can not find data source. Data estimated by VK4GEY.

50 W Semi-Rigid Cable (0.085" dia.): Semi-Rigid cable is intended to be bent and/or formed one time and then left in position. This cable has a solid copper outer conductor (tube). Some versions are silver plated. This version has an exterior diameter of .086" (2.18 mm) and a solid copper inner conductor. SMA, SMC or TNC connectors can be used and are easily installed. Losses are superior to flexible cables.

Band:	*Frequency:*	Attenuation (dB/100 m):		*Attenuation (dB/m):*	
1	30 MHz	13.0	dB/100m	0.13	dB/m
2	145 MHz	25.0	dB/100m	0.25	dB/m
3	435 MHz	33.0	dB/100m	0.33	dB/m
4	1270 MHz	53.0	dB/100m	0.53	dB/m
5	2000 MHz	**88.6**	dB/100m	**0.89**	dB/m
6	2400 MHz	96.0	dB/100m	0.96	dB/m
7	10,000 MHz	**200.1**	dB/100m	**2.00**	dB/m
8	18,000 MHz	**275.5**	dB/100m	**2.76**	dB/m

Band: 3
Frequency: 435 MHz
Cable Length: 0.50 m
Cable Loss: 0.17 dB
NOTE:
Data courtesy Storm Products Co. [**Bold Text**].
Data extrapolated by VK4GEY

50 W Semi-Rigid Cable (0.141" dia.): Semi-Rigid cable is intended to be bent and/or formed one time and then left in position. This cable has a solid copper outer conductor (tube). Some versions are silver plated. This version has an exterior diameter of 0.141" (3.58 mm) and a solid copper inner conductor. SMA, SMC or TNC connectors can be used and are easily installed. Losses are superior to flexible cables.

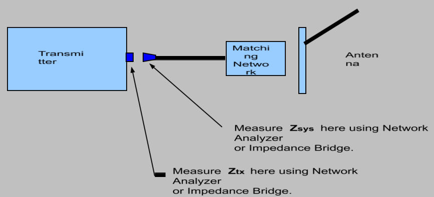
Band:	*Frequency:*	Attenuation (dB/100 m):		*Attenuation (dB/m):*	
1	30 MHz	8.0	dB/100m	0.08	dB/m
2	145 MHz	15.0	dB/100m	0.15	dB/m
3	435 MHz	24.0	dB/100m	0.24	dB/m
4	1270 MHz	57.5	dB/100m	0.58	dB/m
5	2000 MHz	**65.6**	dB/100m	**0.66**	dB/m
6	2400 MHz	68.5	dB/100m	0.69	dB/m
7	10,000 MHz	**91.8**	dB/100m	**0.92**	dB/m
8	18,000 MHz	**124.6**	dB/100m	**1.25**	dB/m

Band: 7
Frequency: 10000 MHz
Cable Length: 0.50 m
Cable Loss: 0.46 dB
NOTE:
Data courtesy Storm Products Co.[**Bold Text**].
Data extrapolated by VK4GEY

Losses Resulting from Antenna Mismatch - Measured Using Voltage Standing Wave Ratio(VSWR) Method

NOTE:

Transmitter Power Output:	2.0 watts		
Measured or Estimated VSWR:	1.6 :1		Manually Enter Results of Test #1 or Test #2 at Cell [H8]
Power Reflected and Lost:	0.11 watts	5.3%	% of Power
Power Transmitted:	1.89 watts	94.7%	% of Power
Power Loss due to Mismatch (dB):	**0.24** dB		This value should be entered in the "Transmitters" W/S at Cell [I31].



TEST CONFIGURATION #1

Measured Z_{tx}: 50 + 0.0 j

Measured Z_{sys}: 75 + -25.0 j

VSWR: 1.58 :1

TEST 1

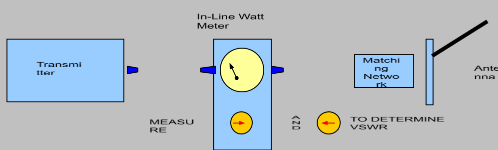
OR

TEST 2

Forward Power Measured: 5.0 watts

Reverse Power Measured: 0.25 watts

VSWR: 1.58 :1



NOTE:

TEST CONFIGURATION #2

Don't Change These Formulas

$|Z_{tx}|$ = 50.0 W

$|Z_{sys}|$ = 79.1 W

NOTE:

GEO Azimuth Calculation:

User #1:

User is:				
Latitude	**19.062** °			
In N. Hem?	1			Satellite is to South if "1", North if "0"
	0			Satellite is to North if "1", South if "0"
D Longitude	**-16.626** °			
East of Sat?	0			Satellite is to West if "1", East if "0"
	1			Satellite is to East if "1", West if "0"
	Sat. in Quad?	Quad. Result:		Quad. Angle Range:
Quad NE	0	0.000	°	0° to 90°
Quad SE	1	137.564	°	90° to 180°
Quad SW	0	0.000	°	180° to 270°
Quad NW	0	0.000	°	270° to 360°
Azimuth Calc.	**42.436** °			
Azimuth Result:		137.564	°	

User #2:

User is:				
Latitude	**17.429** °			
In N. Hem?	1			Satellite is to South if "1", North if "0"
	0			Satellite is to North if "1", South if "0"
D Longitude	**-11.034** °			
East of Sat?	0			Satellite is to West if "1", East if "0"
	1			Satellite is to East if "1", West if "0"
	Sat. in Quad?	Quad. Result:		Quad Angle Range:
Quad NE	0	0.000	°	0° to 90°
Quad SE	1	146.935	°	90° to 180°
Quad SW	0	0.000	°	180° to 270°
Quad NW	0	0.000	°	270° to 360°
Azimuth Calc.	**33.065** °			
Azimuth Result:		146.935	°	

Earth and Orbit Shape for Figure in Orbit & Frequency W/S **[NOTE: DO NOT MODIFY]**

NOTE:	Y	X	R	Y1	X1	R1
	.51994318	-1.9	16	.5745629	-1.9	16.2
	.54647712	-1.85	16	3.6	-1.85	16.2
	.5721142	-1.8	16	.6245689	-1.8	16.2
	.59687364	-1.75	16	.64828726	-1.75	16.2
	.62077339	-1.7	16	.67117147	-1.7	16.2
	.64383040	-1.65	16	.69323706	-1.65	16.2
	.66606055	-1.6	16	.7144986	-1.6	16.2
	.68747881	-1.55	16	.73496987	-1.55	16.2
	.70809924	-1.5	16	.75466376	-1.5	16.2
	.72793508	-1.45	16	.77359245	-1.45	16.2
	.74699879	-1.4	16	.79176739	-1.4	16.2
	.76530211	-1.35	16	.80919939	-1.35	16.2
	.78285606	-1.3	16	.82589858	-1.3	16.2
	.79967103	-1.25	16	.84187454	-1.25	16.2
	.81575680	-1.2	16	.85713624	-1.2	16.2
	.83112255	-1.15	16	.87169213	-1.15	16.2
	.84577690	-1.1	16	.88555015	-1.1	16.2
	.8597279	-1.05	16	.89871773	-1.05	16.2
	.87298334	-1	16	.91120186	-1	16.2
	.88555015	-0.95	16	.92300904	-0.95	16.2
	.89743505	-0.9	16	.93414539	-0.9	16.2
	.90864426	-0.85	16	.94461658	-0.85	16.2
	.91918358	-0.8	16	.95442789	-0.8	16.2
	.92905841	-0.75	16	.96358423	-0.75	16.2
	.93827373	-0.7	16	.9720901	-0.7	16.2
	.94683417	-0.65	16	3.979950	-0.65	16.2
	.95474398	-0.6	16	.98716691	-0.6	16.2
	.96200706	-0.55	16	.9937451	-0.55	16.2
	.96862696	-0.5	16	.99968748	-0.5	16.2
	.97460689	-0.45	16	.00499687	-0.45	16.2
	.97994974	-0.4	16	.00967579	-0.4	16.2
	.98465807	-0.35	16	.01372644	-0.35	16.2
	.98873413	-0.3	16	.01715073	-0.3	16.2
	.99217985	-0.25	16	.01995024	-0.25	16.2
	.99499687	-0.2	16	.02212630	-0.2	16.2
	.99718651	-0.15	16	.02367990	-0.15	16.2
	.99874980	-0.1	16	.02461178	-0.1	16.2
	.99968748	-0.05	16	.02492235	-0.05	16.2
	4.000000	0	16	4.0249223	0	16.2
	3.9996874	0.05	16	4.0246117	0.05	16.2
	3.9987498	0.1	16	4.0236799	0.1	16.2
	3.9971865	0.15	16	4.0221263	0.15	16.2
	3.9949968	0.2	16	4.0199502	0.2	16.2
	3.9921798	0.25	16	4.0171507	0.25	16.2
	3.9887341	0.3	16	4.0137264	0.3	16.2
	3.9846580	0.35	16	4.0096757	0.35	16.2
	3.9799497	0.4	16	4.0049968	0.4	16.2
	3.9746068	0.45	16	3.9996874	0.45	16.2
	3.9686269	0.5	16	3.9937451	0.5	16.2
	3.9620070	0.55	16	3.9871669	0.55	16.2
	3.9547439	0.6	16	3.9799497	0.6	16.2
	3.9468341	0.65	16	3.9720901	0.65	16.2
	3.9382737	0.7	16	3.9635842	0.7	16.2
	3.9290584	0.75	16	3.9544278	0.75	16.2
	3.9191835	0.8	16	3.9446165	0.8	16.2
	3.9086442	0.85	16	3.9341453	0.85	16.2
	3.8974350	0.9	16	3.9230090	0.9	16.2
	3.8855501	0.95	16	3.9112018	0.95	16.2
	3.8729833	1	16	3.8987177	1	16.2
	3.8597279	1.05	16	3.8855501	1.05	16.2
	3.8457769	1.1	16	3.8716921	1.1	16.2
	3.8311225	1.15	16	3.8571362	1.15	16.2
	3.8157568	1.2	16	3.8418745	1.2	16.2
	3.7996710	1.25	16	3.8258985	1.25	16.2
	3.7828560	1.3	16	3.8091993	1.3	16.2
	3.7653021	1.35	16	3.7917673	1.35	16.2
	3.7469987	1.4	16	3.7735924	1.4	16.2
	3.7279350	1.45	16	3.7546637	1.45	16.2
	3.7080992	1.5	16	3.7349698	1.5	16.2
	3.6874788	1.55	16	3.7144986	1.55	16.2
	3.6660605	1.6	16	3.6932370	1.6	16.2
	3.6438304	1.65	16	3.6711714	1.65	16.2
	3.6207733	1.7	16	3.6482872	1.7	16.2
	3.5968736	1.75	16	3.6245689	1.75	16.2
	3.5721142	1.8	16	3.6	1.8	16.2
	3.5464771	1.85	16	3.5745629	1.85	16.2
	3.5199431	1.9	16	3.548239	1.9	16.2