

# **Plishner Radio Astronomy and Space Science Center**

## **The Use of Monte-Carlo Analysis to Evaluate Radio Astronomy Source Detection**

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### **Abstract**

The Plishner Radio Astronomy and Space Science Center is operated by the Deep Space Exploration Society based out of Colorado Springs, Colorado. Monte-Carlo analysis uses multiple iterations to evaluate all ranges of variables in a systems performance. The 1420 MHz receiving system for the Plishner Radio Astronomy and Space Science Center 60-foot dish system was evaluated. This analysis shows the antenna and receiving system component performance ranges and the effect of each against the expected signal source detection capability.

### **1.0 Introduction**

The Deep Space Exploration Society (DSES) is a not for profit organization whose primary purposes are research and education of space communications and radio astronomy. The DSES primary asset is the Plishner Radio Astronomy and Space Science Center which is located in a radio quiet area near Haswell, Colorado. The primary asset of the DSES organization is a 60-foot parabolic reflector that was built in the 1950s for the study of tropospheric communications.

The 1420 MHz receiving system for the Plishner Radio Astronomy and Space Science Center 60-foot dish system [1] was evaluated using the Monte-Carlo (MC) modeling. This analysis shows the antenna and receiving system component performance ranges and the effect of each against the expected signal source detection capability. The example for this analysis uses Mars as a source [2] to demonstrate the capability of the MC model to characterize sources with multiple variables that are continuously varying.

### **2.0 Monte-Carlo (MC) Analysis Model**

**“Monte Carlo methods (or Monte Carlo experiments) are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results.”** [3]

MC modeling has been used for radio astronomy in the past. [4] [5] [6] [7] These papers used MC modeling because of the complex number of variables and the interrelationships of multiple formulas used required to be analyzed for radio astronomy measurements.

#### **2.1 Monte-Carlo Model Development**

A MC model was developed using Microsoft Excel. The model uses the Excel visual basic tool to provide a loop and data capture capability. The visual basic program used is shown below. (figure 1)

```

Sub Test1()
Dim A(1 To 100000) As Double
Dim B(1 To 100000) As Double
Dim C(1 To 100000) As Double
Dim D(1 To 100000) As Double
Dim E(1 To 100000) As Double
Dim F(1 To 100000) As Double
Dim G(1 To 100000) As Double
Dim H(1 To 100000) As Double
Dim I(1 To 100000) As Double
Dim J(1 To 100000) As Double
Dim K(1 To 100000) As Double
Dim L(1 To 100000) As Double
Dim M(1 To 100000) As Double

Dim O(1 To 100000) As Double
Dim P(1 To 100000) As Double
Dim Q(1 To 100000) As Double
Dim R(1 To 100000) As Double
Dim S(1 To 100000) As Double
Dim T(1 To 100000) As Double
Dim U(1 To 100000) As Double
Dim V(1 To 100000) As Double
Dim W(1 To 100000) As Double
Dim X(1 To 100000) As Double
Dim Y(1 To 100000) As Double
Dim Z(1 To 100000) As Double

```

```

For N = 1 To Range("B2").Value
Calculate
A(N) = Range("K5").Value ' Mars Distance from Sun (AU)
B(N) = Range("K12").Value ' Frequency (Hz)
C(N) = Range("K14").Value ' Mars Distance from Earth (AU)
D(N) = Range("K17").Value ' Mars Reflectivity
E(N) = Range("K19").Value ' Plishner Antenna Diameter (m)
F(N) = Range("K20").Value ' Antenna Efficiency
G(N) = Range("K21").Value ' Trx
H(N) = Range("K22").Value ' Tcmb
I(N) = Range("K23").Value ' Tactm
J(N) = Range("K24").Value ' Tspillover
K(N) = Range("K25").Value ' Bandwidth (Hz)
L(N) = Range("K26").Value ' Noise Factor
M(N) = Range("K27").Value ' Iterations (n)
O(N) = Range("K28").Value ' Observation Time (seconds)
P(N) = Range("K29").Value ' Tref

Q(N) = Range("I32").Value ' Luminosity of Sun
R(N) = Range("I33").Value ' Tmars
S(N) = Range("I34").Value ' Tmars (adjusted for reflectivity)
T(N) = Range("I35").Value ' Mars (arcseconds)
U(N) = Range("I36").Value ' Sm (Mars Flux Density)

V(N) = Range("I40").Value ' Full Wave Theta degrees
W(N) = Range("I41").Value ' Antenna effective
X(N) = Range("I42").Value ' Tantenna
Y(N) = Range("I43").Value ' Tsystem

```

'Print results on Results Tab

```

Worksheets("Results").Cells(N + 1, 1) = N
Worksheets("Results").Cells(N + 1, 2) = A(N)
Worksheets("Results").Cells(N + 1, 3) = B(N)
Worksheets("Results").Cells(N + 1, 4) = C(N)
Worksheets("Results").Cells(N + 1, 5) = D(N)
Worksheets("Results").Cells(N + 1, 6) = E(N)
Worksheets("Results").Cells(N + 1, 7) = F(N)
Worksheets("Results").Cells(N + 1, 8) = G(N)
Worksheets("Results").Cells(N + 1, 9) = H(N)
Worksheets("Results").Cells(N + 1, 10) = I(N)
Worksheets("Results").Cells(N + 1, 11) = J(N)
Worksheets("Results").Cells(N + 1, 12) = K(N)
Worksheets("Results").Cells(N + 1, 13) = L(N)
Worksheets("Results").Cells(N + 1, 14) = M(N)
Worksheets("Results").Cells(N + 1, 15) = O(N)
Worksheets("Results").Cells(N + 1, 16) = P(N)
Worksheets("Results").Cells(N + 1, 17) = Q(N)
Worksheets("Results").Cells(N + 1, 18) = R(N)
Worksheets("Results").Cells(N + 1, 19) = S(N)
Worksheets("Results").Cells(N + 1, 20) = T(N)
Worksheets("Results").Cells(N + 1, 21) = U(N)
Worksheets("Results").Cells(N + 1, 22) = V(N)
Worksheets("Results").Cells(N + 1, 23) = W(N)
Worksheets("Results").Cells(N + 1, 24) = X(N)
Worksheets("Results").Cells(N + 1, 25) = Y(N)
Worksheets("Results").Cells(N + 1, 26) = Z(N)

```

text N

Figure 1: MC Visual Basic Program

The program is loaded as a macro and tied to the worksheet called "Control Panel". The macro is initiated using a "Form Control". The number of iterations (N) was empirically selected as 500 to allow for fast processing time. The inputs are captured on the "Control Panel" worksheet. The outputs of the program go to the "Results" worksheet, using one column per variable and one row per iteration.

The inputs in the "Control Panel" have a user entry of "minimum" and "maximum". The program randomly selects between these two values and sends the result as the input to the algorithms. For each of the 500 loops, the random numbers recalculate, and therefore provides different inputs and outputs for each iteration. The

500 iteration results, therefore contain the full range of possibilities, which can be analyzed using basic statistical tools and plots.

## 2.3 Formula development

A set of multi-variable formulas were chosen to demonstrate the MC modeling capability. The formulas chosen were based on the National Radio Astronomy Observatory ASTR 534 tutorial. [8] The tutorial details the equations for calculating the flux density of Mars at a given frequency and at the closest approach to Earth. The MC model uses these equations and allows for the selection of ranges of the input variables such as distance from Earth, observed frequency, and the reflectivity of the Mars surface. The equations used (Formula) and instantaneous solutions (Value) are shown in figure 2.

Source Calculations			
Parameter	Value	Units	Formula
Bolometric Luminosity of Sun	3.91E+26	Watts	$L_{\odot} = 4\pi R_{\odot}^2 \sigma T^4$
Tm	226.94	K	$T_M = \sqrt[4]{\frac{R_{\odot}^2}{4d^2} L_{\odot}}$
Tm (with reflectivity)	204.25	K	$T_m = (1 - r)T$
Mars arcsec	13.7332	"	$\theta_{arcsec} = [\sinh(\frac{R_m}{d})(\frac{180}{\pi})(3600)(2)]$
Sm	0.14	JY	$S_m = B_{\nu} \Omega = \frac{2kTf^2}{c^2} \left( \frac{\pi (Mars_{arcsec} 4.84 \times 10^{-6})^2}{4} \right)$

Figure 2: Mars Formulas to Calculate Flux Density

## 2.4 Variable Inputs

The variables were placed in a “Control Panel” which allowed for the ranges of each variable to be entered as a maximum and minimum (figure 3).

Control Panel Inputs				
Parameter	Min	Max	Random	Units
Bolometric Luminosity of Sun	3.85E+26	3.85E+26	3.85E+26	Watts
Stephan -Boltzmann Constant	5.67E-08	5.67E-08	5.67E-08	W/(m <sup>2</sup> K <sup>4</sup> )
Sun Radius	6.96E+08	6.96E+08	6.96E+08	m
Sun Temperature	5.80E+03	5.80E+03	5.80E+03	K
Mars distance from Sun (AU)	1.52E+00	1.52E+00	1.52E+00	AU
1 AU	1.50E+11	1.50E+11	1.50E+11	m
Boltzmanns Constant (k)	1.38E-23	1.38E-23	1.38E-23	J/K
frequency	4.00E+08	1.50E+10	2.57E+09	Hz
Speed of Light c	3.00E+08	3.00E+08	3.00E+08	m/s
Mars Distance from Earth (AU)	0.524	0.800	0.682	AU
arcseconds to radians	4.84E-06	4.84E-06	4.84E-06	1" = x radians
JY conversion	1.00E-26	1.00E-26	1.00E-26	
Mars Reflectivity	10%	10%	10%	%

Figure 3: Control Panel

The user input variable ranges are shown in yellow. The column labeled “Random” uses the following formula.

$$=\text{Min} + (\text{Max}-\text{Min})*\text{rand}()$$

This formula randomly selects a value between the minimum and maximum values inclusive for each iteration loop. The values in the random column are then applied to the equations in figure 2 with calculation results shown in the “value” column. For each loop the visual basic program captures the values of all input variables and formula values and maps them on the “Results” worksheet. A small portion of the “Results Worksheet” is shown in figure 4.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Iteration #	Mars Distance from Sun	Frequency (Hz)	Mars Distance from Earth (AU)	Mars Reflectivity	Antenna Diameter (m)	Antenna Efficiency	T <sub>rx</sub> (K)	T <sub>amb</sub> (K)	T <sub>atm</sub> (K)	Telescope (K)	Bandwidth (Hz)	Noise Factor	Iterations (n)	Observation Time (seconds)	T <sub>ref</sub> (K)	Luminosity of Sun	T <sub>mass</sub> (K)	T <sub>mass w/ reflectivity</sub>	Mars arcseconds	Mars Flux
1	3.85E+26	1.00E+10	2.63	10%	25.0	0.7	18.0	3.0	3.0	11.0	1.00E+08	1.10	1	1.0	290.00	3.9E+26	226.9	204.2	3.6	
2	3.85E+26	1.00E+10	1.59	10%	25.0	0.7	18.0	3.0	3.0	11.0	1.00E+08	1.10	1	1.0	290.00	3.9E+26	226.9	204.2	5.3	
3	3.85E+26	1.00E+10	0.61	10%	25.0	0.7	18.0	3.0	3.0	11.0	1.00E+08	1.10	1	1.0	290.00	3.9E+26	226.9	204.2	11.6	
4	3.85E+26	1.00E+10	3.22	10%	25.0	0.7	18.0	3.0	3.0	11.0	1.00E+08	1.10	1	1.0	290.00	3.9E+26	226.9	204.2	2.3	
5	3.85E+26	1.00E+10	2.42	10%	25.0	0.7	18.0	3.0	3.0	11.0	1.00E+08	1.10	1	1.0	290.00	3.9E+26	226.9	204.2	3.3	
6	3.85E+26	1.00E+10	3.08	10%	25.0	0.7	18.0	3.0	3.0	11.0	1.00E+08	1.10	1	1.0	290.00	3.9E+26	226.9	204.2	3.0	
7	3.85E+26	1.00E+10	0.74	10%	25.0	0.7	18.0	3.0	3.0	11.0	1.00E+08	1.10	1	1.0	290.00	3.9E+26	226.9	204.2	12.6	
8	3.85E+26	1.00E+10	0.74	10%	25.0	0.7	18.0	3.0	3.0	11.0	1.00E+08	1.10	1	1.0	290.00	3.9E+26	226.9	204.2	12.7	
9	3.85E+26	1.00E+10	3.40	10%	25.0	0.7	18.0	3.0	3.0	11.0	1.00E+08	1.10	1	1.0	290.00	3.9E+26	226.9	204.2	2.8	

Figure 4: Results Worksheet Example

## 2.4 Results Modeling

The results worksheet contains the inputs and outputs of the model for a 500-iteration set of samples for the input ranges between maximum and minimum. This allows for plotting of any combination of inputs or outputs.

### 2.4.1 Percentage Table and Plot

The Percentage plot uses the “percentile” excel formula. This formula queries all 500 iterations and returns the value of the parameter that has achieved a given percentage of the results. For example, a percentile of 60% means that 500 x 60% = 300 results came in below that value. The percentile table (figure 5) demonstrates the relationships of a set of parameters.

The results in figure 5 show what the relationship of combining the Mars-Earth distance, frequency, and Mars reflectivity as inputs to the Mars flux density calculation.

Parameter	Control Panel Inputs			Units
	Min	Max	Random	
Bolometric Luminosity of Sun	3.85E+26	3.85E+26		Watts
Stefan-Boltzmann Constant	5.67E-08	5.67E-08		W/(m <sup>2</sup> ·K <sup>4</sup> )
Sun Radius	6.96E+08	6.96E+08		m
Sun Temperature	5.80E+03	5.80E+03		K
Mars distance from Sun (AU)	1.52E+00	1.52E+00		AU
1AU	1.50E+11	1.50E+11		m
Boltzmanns Constant (k)	1.38E-23	1.38E-23		J/K
Frequency	4.00E+08	1.50E+10		Hz
Speed of Light c	3.00E+08	3.00E+08		m/s
Mars Distance from Earth (AU)	0.524	3.524		AU
arcseconds to radians	4.84E-06	4.84E-06		1° = x radians
JY conversion	1.00E-26	1.00E-26		W/m <sup>2</sup>
Mars Reflectivity	0%	10%		%

Percentile	Mars-Earth Distance (AU)	Frequency (Hz)	Reflectivity %	Smars (JY)
100%	0.542	1.50E+10	0.0%	5.85
90%	0.838	1.34E+10	1.0%	1.08
80%	1.097	1.18E+10	2.0%	0.48
70%	1.452	1.05E+10	3.0%	0.30
60%	1.759	9.03E+09	4.2%	0.20
50%	2.100	7.52E+09	5.2%	0.14
40%	2.409	5.90E+09	6.0%	0.09
30%	2.680	4.63E+09	7.2%	0.05
20%	2.936	3.14E+09	8.2%	0.03
10%	3.254	1.64E+09	9.2%	0.01
0%	3.507	4.19E+08	10.0%	0.00

Figure 5: Input Ranges and Percentile Table

The results in figure 5 indicate that the Mars flux density increases with both a higher frequency and a lower distance between Mars and Earth. The higher the reflectivity of Mar’s surface also results in lower flux density.

### 2.4.2 Single Variable Modeling

The MC model allows for single variable as well as multiple variable modeling. The distance between Mars and Earth can be roughly estimated using the mean distance between Mars and the Sun is 1.524 astronomical unit (AU) and the mean distance between Earth and the Sun is 1.0 AU [9]. For simplicity, the assumption is that both planets are in a circular orbit as shown in Figure 6.

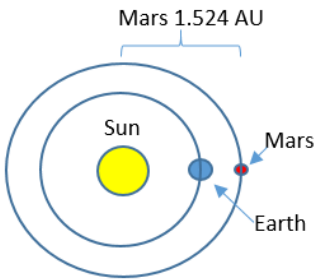


Figure 6: Mars and Earth Distance Model

The closest approach of Mars to Earth is  $1.524 \text{ AU} - 1.000 \text{ AU} = 0.524 \text{ AU}$ . The farthest distance is when the Earth is on the other side of the Sun which is 2.524 AU away. Note, that the Sun will block the signals before it gets that far, but this gives a rough estimate to establish the Mars-Earth range variable minimum and maximum. The flux density was then calculated by only changing the Mars -Earth distance and keeping all other parameters constant. The “control panel” and Flux Density vs. Mars-Earth distance is shown in figure 7.

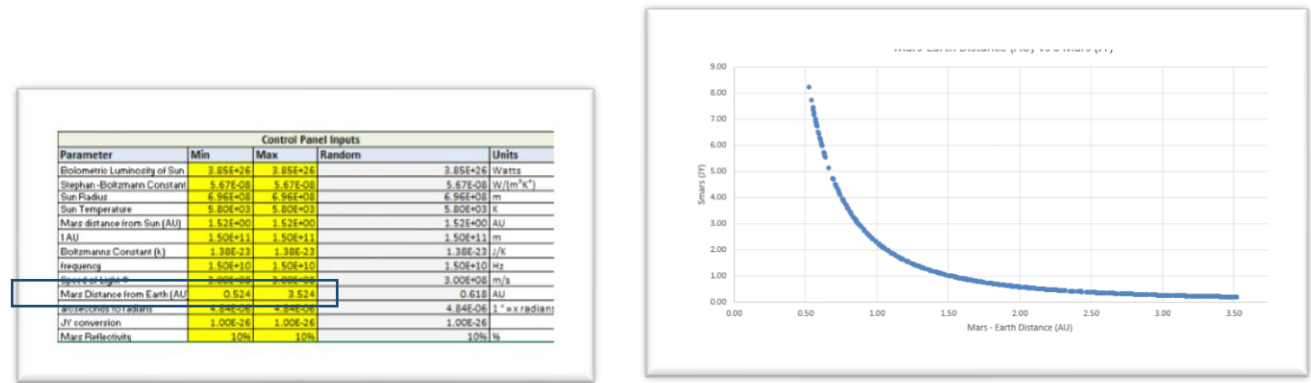


Figure 7: Flux Density (Smars) (JY) vs. Mars-Earth Distance (AU) (only varying distance)

The MC model, however allows for multiple variable ranges. If the minimum and maximum ranges for frequency and reflectivity are added, the results look like figure 8. This shows how the frequency and reflectivity spread out the results of the flux density for the same Mars-Earth distances.

Control Panel Inputs				
Parameter	Min	Max	Random	Units
Bolometric Luminosity of Sun	3.85E+26	3.85E+26	3.85E+26	Watts
Stefan-Boltzmann Constant	5.67E-08	5.67E-08	5.67E-08	W/(m <sup>2</sup> K <sup>4</sup> )
Sun Radius	6.96E+08	6.96E+08	6.96E+08	m
Sun Temperature	5.80E+03	5.80E+03	5.80E+03	K
Mars distance from Sun (AU)	1.52E+00	1.52E+00	1.52E+00	AU
1 AU	1.50E+11	1.50E+11	1.50E+11	m
Bolometric Flux Density	1.38E-23	1.38E-23	1.38E-23	J/K
Frequency	1.42E+09	1.50E+10	1.03E+10	Hz
Speed of Light c	3.00E+08	3.00E+08	3.00E+08	m/s
Mars Distance from Earth (AU)	0.524	3.524	3.454	AU
arcseconds to radians	4.84E-06	4.84E-06	4.84E-06	1" = x radians
IV conversion	1.00E-28	1.00E-28	1.00E-28	
Mars Reflectivity	0%	10%	7%	%

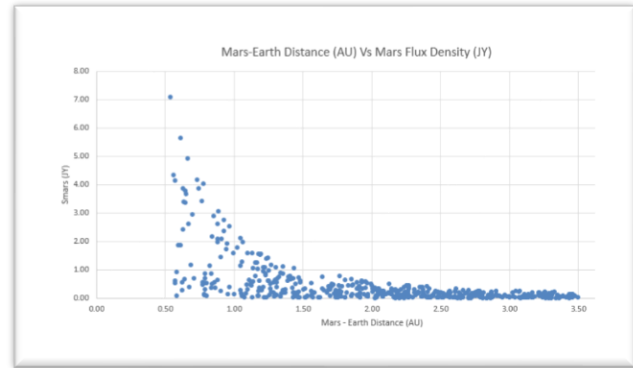


Figure 8: Multivariate Ranging Example

The relationship between Flux density and frequency as well as reflectivity can also be plotted. Note that the results still include the relationships between all of the variable ranges.

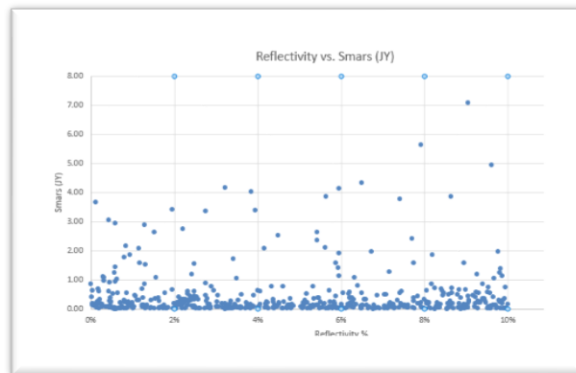
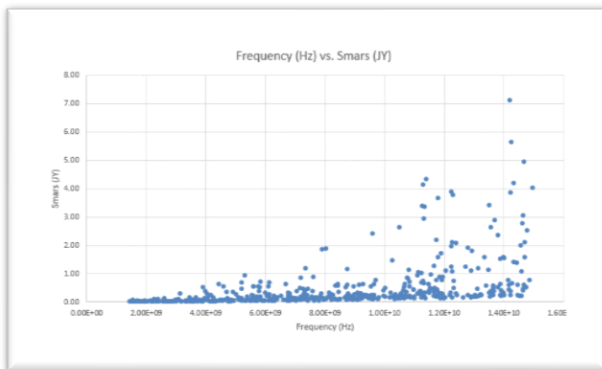


Figure 9: Mars Flux Density vs. frequency and reflectivity plots

### 3.0 Plishner System Modeling

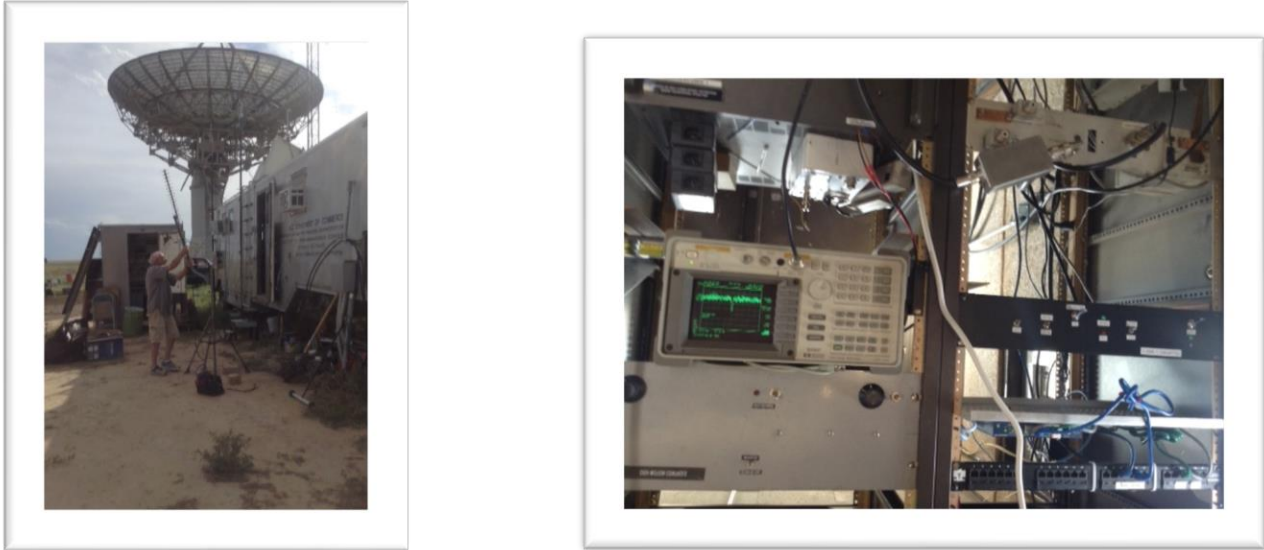
The Plishner 60-foot parabolic dish (figure 10) is being outfitted with a multi-band feed. [1]



Figure 10: DSES 60 ft. Dish



A communications trailer is located next to the antenna pedestal. All receiver equipment is located in the trailer. This allows for shorter feed lines. Remote access to the communications trailer is available through the internet to allow for control and monitoring of radio and power systems. (figure 11)



*Figure 11: Communications Trailer and Test Rack*

The feed is mounted as a prime focus (figure 12) and is capable of receiving 1420, 1296, 435, and 144 MHz bands. It is also capable of transmitting 1296, 435, and 144 MHz bands for use with Earth-Moon-Earth (EME) and tropospheric communications. [1].



*Figure 12: Multiband Feed*

### 3.1 Radio Telescope Formula Development

The formula for the minimum flux density ( $S_{min}$ ) needed for the antenna and receiver system to “see” an astronomical source is [10] [11]:

$$S_{min} = \frac{2kT_{ref}NF}{A_e\sqrt{n\tau(\Delta f)}}$$

A = antenna area in square meters  
K = Boltzmann's Constant =  $1.38 \times 10^{-23}$   
T = 290 °K

$N$  = Noise Factor = 1.1  
 $n$  = number of records averaged  
 $\tau$  = time constant of integration  
 $\Delta f$  = Bandwidth (Hz)  
 $1 \text{ JY} = 10^{-26} \text{ Wm}^2\text{Hz}^{-1}$

The input parameter “control panel” and the formulas and solutions (Value) for the radio telescope are shown in figure 14.



Figure 13: Radio Telescope Input Variables and Calculations

### 3.2 Telescope Single Variable Analysis

The radio telescope sensitivity varies with bandwidth and integration constant. Figures 15 and 16 show how each input parameter changes  $S_{min}$  while maintaining other input parameters constant.

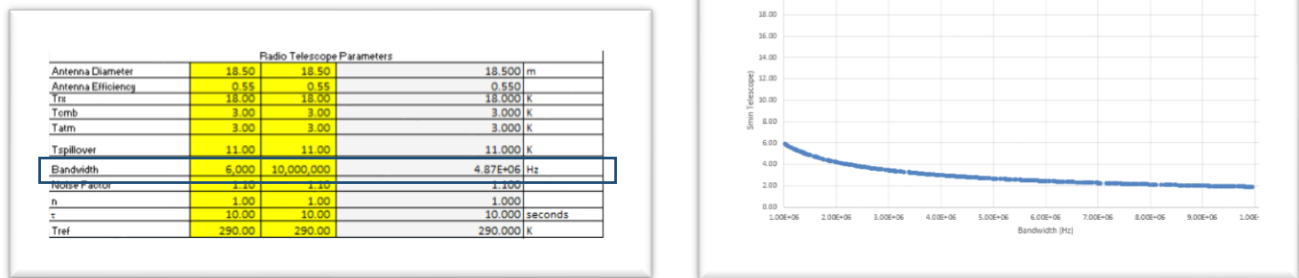


Figure 14: Smin (telescope) (JY) vs. Bandwidth (Hz)



Radio Telescope Parameters			
Antenna Diameter	18.50	18.50	18.500 m
Antenna Efficiency	0.55	0.55	0.550
T <sub>ra</sub>	18.00	18.00	18.000 K
T <sub>omb</sub>	3.00	3.00	3.000 K
T <sub>atm</sub>	3.00	3.00	3.000 K
T <sub>spillover</sub>	11.00	11.00	11.000 K
Bandwidth	10,000,000	10,000,000	1.00E+07 Hz
Noise Factor	1.10	1.10	1.100
n	1.00	1.00	1.000
t	1.00	10.00	9.218 seconds
T <sub>ref</sub>	290.00	290.00	290.000 K

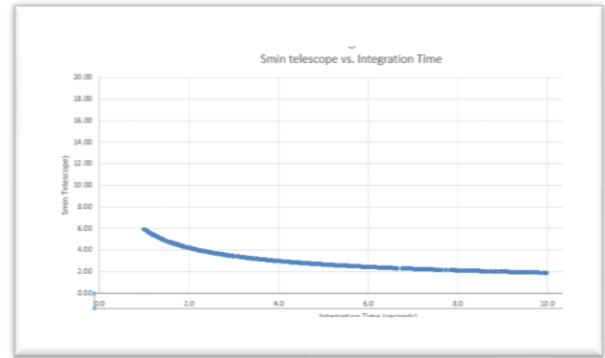


Figure 15: Smin (Telescope) (JY) vs. Integration time (seconds)

The percentile table and plot is used to view the ranging bandwidth and integration time simultaneously. (figure 17)

Radio Telescope Parameters			
Antenna Diameter	18.50	18.50	18.500 m
Antenna Efficiency	0.55	0.55	0.550
T <sub>ra</sub>	18.00	18.00	18.000 K
T <sub>omb</sub>	3.00	3.00	3.000 K
T <sub>atm</sub>	3.00	3.00	3.000 K
T <sub>spillover</sub>	11.00	11.00	11.000 K
Bandwidth	6,000	10,000,000	1.05E+06 Hz
Noise Factor	1.10	1.10	1.100
n	1.00	1.00	1.000
t	1.00	10.00	2.430 seconds
T <sub>ref</sub>	290.00	290.00	290.000 K

Percentile	Integration Time (seconds)	Bandwidth (Hz)	Smin (JY) Telescope
100%	1.0	9.56E+03	72.60
90%	2.0	8.92E+05	10.60
80%	2.8	1.73E+06	6.87
70%	3.7	2.60E+06	5.62
60%	4.6	3.69E+06	4.73
50%	5.4	4.66E+06	4.13
40%	6.3	5.85E+06	3.68
30%	7.3	6.88E+06	3.23
20%	8.1	7.97E+06	2.84
10%	9.0	9.13E+06	2.44
0%	10.0	9.99E+06	1.96

Figure 16: Telescope Sensitivity varying BW and Integration Time

### 3.3 Combining Astronomical Source and Telescope Sensitivity Analysis

The percentile charts (figure 18) provides insight into the capability of the radio telescope against the astronomical source. This shows all input ranges for the source and telescope.

Control Panel Inputs			
Parameter	Min	Max	Random
Boltzmann's Constant	1.38E-23	1.38E-23	1.38E-23
Stefan-Boltzmann Constant	5.67E-08	5.67E-08	5.67E-08
Sun Radius	6.96E+08	6.96E+08	6.96E+08
Sun Temperature	5778	5778	5778
Mars distance from Sun (AU)	1.52E+00	1.52E+00	1.52E+00
1 AU	1.5E+11	1.5E+11	1.5E+11
Boltzmann Constant (B)	1.38E-23	1.38E-23	1.38E-23
Frequency	1.42E+09	1.5E+09	1.46E+09
Aperture Diameter	18.5	18.5	18.5
Mars distance from Earth (AU)	0.53E+00	0.53E+00	0.53E+00
Reflectivity %	0.25	0.25	0.25
JY conversion	1.00E-26	1.00E-26	1.00E-26
Mars Perihelity	1.28E+00	1.28E+00	1.28E+00
Radio Telescope Parameters			
Antenna Diameter	18.5	18.5	18.5
Antenna Efficiency	0.55	0.55	0.55
FS	18.5	18.5	18.5
Trans	3.00	3.00	3.00
Trans	3.00	3.00	3.00
Aperture	11.00	11.00	11.00
Bandwidth	8.00E+09	10.00E+09	9.00E+09
Noise Factor	1.50	1.50	1.50
n	1.00	1.00	1.00
t	1.00	10.00	6.653
Time	290.000	290.000	290.000

Astronomical Source					Radio Telescope			
Percentile	Mars-Earth Distance (AU)	Frequency (Hz)	Reflectivity %	Smars (JY)	Percentile	Integration Time (seconds)	Bandwidth (Hz)	Smin (JY) Telescope
100%	0.538	1.50E+10	0.0%	5.52	100%	1.0	9.56E+03	72.60
90%	0.826	1.38E+10	1.2%	1.04	90%	2.0	8.92E+05	10.60
80%	1.114	1.25E+10	2.1%	0.62	80%	2.8	1.73E+06	6.87
70%	1.393	1.12E+10	3.3%	0.37	70%	3.7	2.60E+06	5.62
60%	1.709	9.59E+09	4.2%	0.24	60%	4.6	3.69E+06	4.73
50%	2.018	8.33E+09	5.0%	0.18	50%	5.4	4.66E+06	4.13
40%	2.375	7.06E+09	5.9%	0.13	40%	6.3	5.85E+06	3.68
30%	2.715	5.42E+09	7.0%	0.09	30%	7.3	6.88E+06	3.23
20%	2.939	4.22E+09	8.0%	0.05	20%	8.1	7.97E+06	2.84
10%	3.238	2.89E+09	9.2%	0.02	10%	9.0	9.13E+06	2.44
0%	3.513	1.43E+09	10.0%	0.00	0%	10.0	9.99E+06	1.96

Figure 17: Combined Outputs

The percentile plot comparison shows the range of detection capability of the radio telescope against the full range of the Mar's flux density. (figure 19)

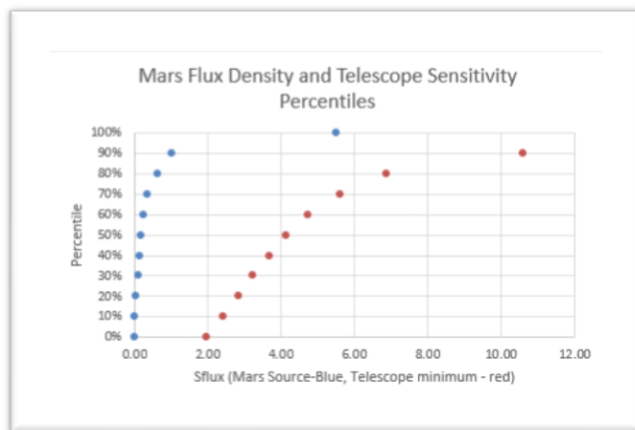


Figure 18: Comparison Plot

### 3.4 Analysis

The results indicate that the Plishner 60-foot dish system has a low probability of detecting Mars using its 1420 MHz feed. Mars flux density increases with frequency and shorter Mars-Earth distances as well as low reflectivity. Mars has higher flux density in the 10-15 GHz frequency range. The Plishner radio telescope currently is not capable of receiving at these frequency ranges.

To increase the probability of detection, the radio telescope needs to measure at the highest frequency possible and increase the bandwidth and integration time to the highest possible. This needs to be combined with the measurement being made at the time of year where the Mars-Earth distance is at its minimum.

Even with the above parameters met, the Plishner radio telescope has a low probability of detecting Mars. The recommendation to modify the telescope for Mars observing is:

- Increase feed capability to 15 GHz
- Increase the bandwidth capability >10 MHz
- Increase the Integration Time > 10 seconds

This is only one example of modeling a radio source against the radio telescope capabilities. The MC model can be used to analyze other telescopes and radio sources with the addition of MC model upgrades.

### 3.5 Future MC Model Upgrades

Future upgrades to this model will provide better accuracy and allow for insight into more parameter relationships.

- Add actual orbital equations for Mars and Earth
  - Better accuracy of distance between planets
- Reflectivity of Mars surface is dependent on frequency
  - Better accuracy on source strength and frequency
- The Sun does not fully reflect back to Earth from Mars during the entire year.
  - Better accuracy on percentage of Mars that can be viewed from Earth which will include the subsequent decrease in flux density
- Add atmospheric opacity characterization
  - Improves accuracy of source flux density
- Provide input parameters in the model for other astronomical sources outside the solar system.

### 4.0 Summary

This paper demonstrated the use of Monte-Carlo modeling to characterize radio astronomy sources and telescopes. MC modeling allows for the use of single variable and multi-variable analysis of all parameters for both the astronomical source the radio telescope. The selection of the ranges of variables allows for the full capability ranges of the telescopes. The results of this analysis allow for telescope design or enhancement recommendations for detection of various astronomical sources that have varying flux density strength parameters.

This paper also identifies various analysis techniques, plots, and tables that assist in the analysis of the MC data. The MC model provides the ability to plot any input and/or output parameter against each other and also determine the probability of any of the outputs from occurring.

The use of MC modeling provides the radio astronomer another tool to understand the detection capability of various astronomical sources using radio telescopes of various capabilities.

The Deep Space Exploration Society is continuing research using the Plishner Radio Astronomy and Space Science Center. Some of this research has been documented in the following references. [10] [11] [12] [1]

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