Automation of the G/T Characterization Measurements for DSS-17

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Abstract

Gain over System Noise Temperature (G/T) is a metric commonly used in radio frequency (RF) engineering to measure the performance of an antenna against the amount of noise contributing to the receiver's signal caused by its internal hardware. While the gain of an antenna is typically inferred geometrically by comparing signal strength of a given antenna to that of an isotropic antenna, system noise temperature must be found experimentally by calibrating the antenna to a black body radiator (in this case, the moon), and comparing the measured power on the black body to that when the antenna is aimed at cold sky. This comparison is measured several times and followed by a sweep in elevation to generate a tip curve which yields a measurement of atmospheric contribution to the signal. From here, G/T can be calculated. The traditional process of measuring system noise temperature introduces room for user error. Writing software which automates the G/T measurement procedure ensures that more accurate data is obtained and reduces the possibility of user error in the procedure. Using Systems Tool Kit (STK) to model Morehead State University's 21-meter deep space antenna, a privately-owned affiliated node on the Deep Space Network[1], as well as Python programming to generate pointing predicts[2], this automation will command DSS-17 to point on and off the moon without the need for users to input pointing commands during the test. This automation will function for both the X-band and S-band frequency feeds utilized on the antenna.

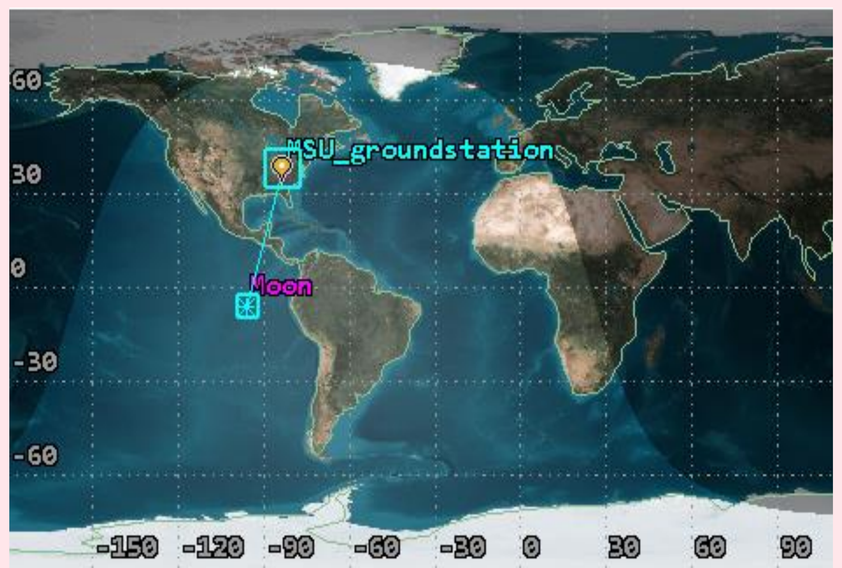
Introduction

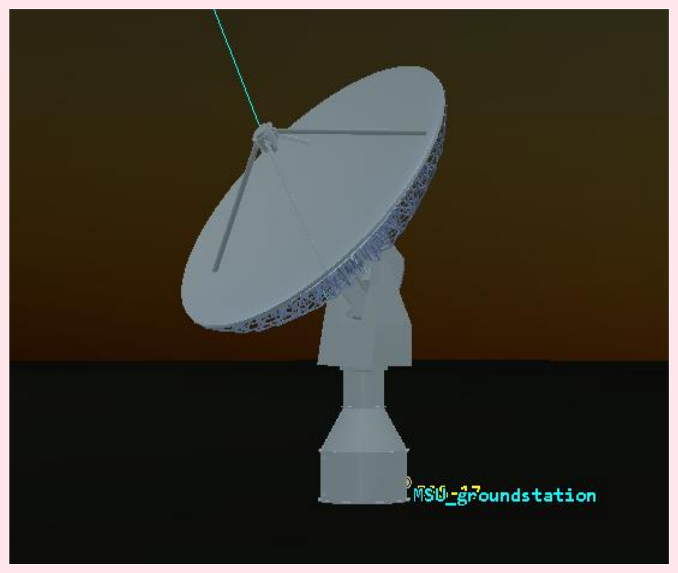
Every object in the universe with a temperature higher than absolute zero radiates electromagnetic energy. Antennas receive this EM radiation as noise. Unfortunately, this means that when an antenna is receiving the signal of an object like a planetary body or a spacecraft, some of the radiation coming from internal equipment feeds back into the signal as noise. This phenomenon is referred to as system noise temperature[3].

Gain is also an important characteristic in the analysis of antenna performance. Gain is defined as the maximum signal strength of an antenna in a particular direction compared to that of an ideal isotropic (omnidirectional) antenna at the same power level. Gain is determined by geometry[3,4], but comparing the gain of different antennas becomes difficult when the antennas are of different dimensions or different reflector geometries (a larger antenna aperture yields higher gain). One can compare the G/T, or gain over system noise temperature, to properly compare efficiencies.

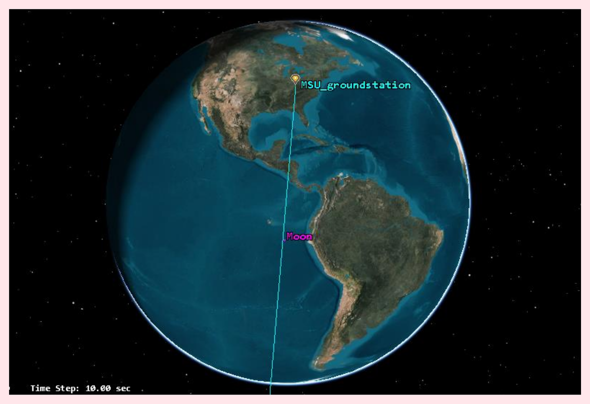
Finding the G/T means experimentally identifying the system noise temperature. This can be done by pointing the antenna at a black body radiator like the moon to calibrate it, followed by adjusting the azimuth (swivel) of the antenna and pointing at "cold sky" on a clear night[4]. Repeating this process in trials to get an average value of power (measured in dBm) and then doing an elevation sweep up to 90 degrees results in a graphical tip curve from which the system noise temperature is derived, and the G/T subsequently calculated.

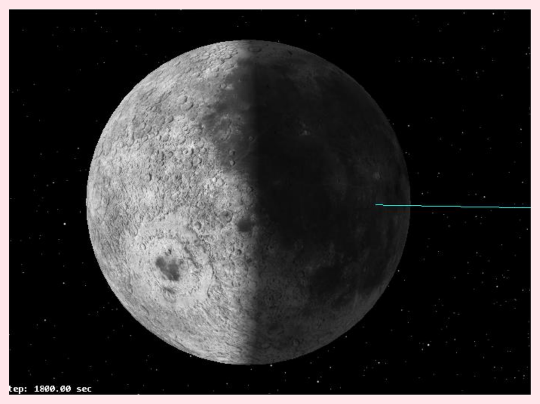
The ground station operations engineers at Morehead State University regularly run G/T tests for DSS-17, the 21-meter parabolic antenna receiver [1] on campus which is an affiliated node on NASA's Deep Space Network. This time-consuming test leaves room for user error. To avoid this, we designed a software which generates a file that commands the antenna to point on and off the moon, eliminating the need for manual user commands. This file is generated based on a report gathered from modeling the Morehead ground station in Systems Tool Kit.





The images below come from the Systems Tool Kit scenario and demonstrate the moon's accessibility from MSU's ground station on Nov 10, 2023 (Phase I Track). The access is modeled by the cyan line and can be viewed from both a 3D model of the Earth and that of the moon. The images above include a 2D Systems Tool Kit model of the moon's accessibility on the same date, as well as a 3D rendering of DSS-17 accessing the moon in mid-February, when Phase II testing occurred. The model of the 21m was designed in SolidWorks at an earlier date by Mike Combs of the MSU Space Science Center. The model was then placed in our STK scenario for visual purposes. The real dish is pictured below.



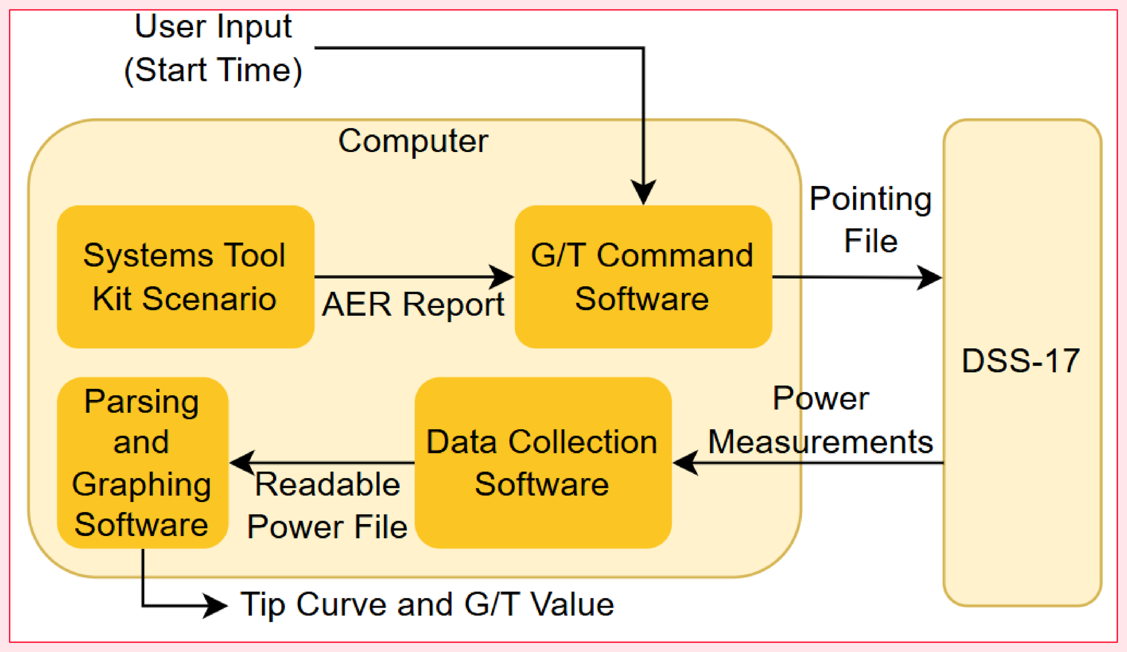


Automation Program Excerpt

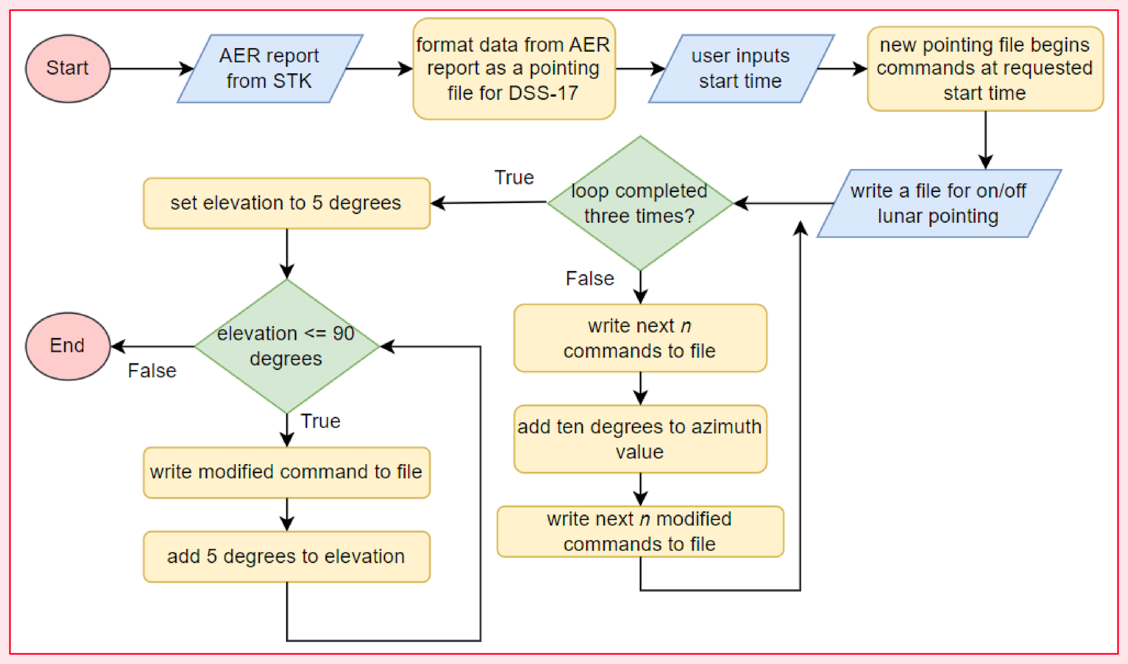
```
                    m.write(rowlist[rowcount]) #first point in trial ON moon
                rowcount += 1 #add to row count
            OFF = 0
            for OFF in range(2): #do off command x times in a row
                if first == 0: #only write to file after rowcount is printed to top
                    m.write(f'{yearlist[rowcount]}{daylist[rowcount]}{timelist[rowcount]}{newazlist[rowcount]}{elevatio
                rowcount += 1 #add to row count

#------------------ELEVATION SWEEP-------------------------------------------------------------------------
        sweep = 5.00000 #begin elevation sweep at 5 degrees
        justifiedsweep_az = f"{sweep_az[0].rjust(8, ' ')}.{sweep_az[1].ljust(5, '0')}"
        while sweep <= 90.00000: #repeat commands until elevation at 90 deg
            sweep = str(sweep).split('.')
            justifiedsweep = f"{sweep[0].rjust(8, ' ')}.{sweep[1].ljust(5, '0')}"
            for E in range(2):
                if first == 0: #write to file after rowcount is printed to top
                    m.write(f'{yearlist[rowcount]}{daylist[rowcount]}{timelist[rowcount]}{sweep_az}{justifiedsweep}\n')
                rowcount += 1 #add to row count
            sweep = float('.'.join(sweep)) + 5.00000 #add 5 degrees for next sweep interval
        if first == 1: #if count is 1
            m.write(f'{rowcount}\n') #write rowcount to top of file
            rowcount = 0 #set rowcount back to 0
            sweep = 5.00000 #reset sweep variable back to 5.0000 to reset sweep loop
            first = 0 #set count to 0 so it loops through, actually writing to file this time
```

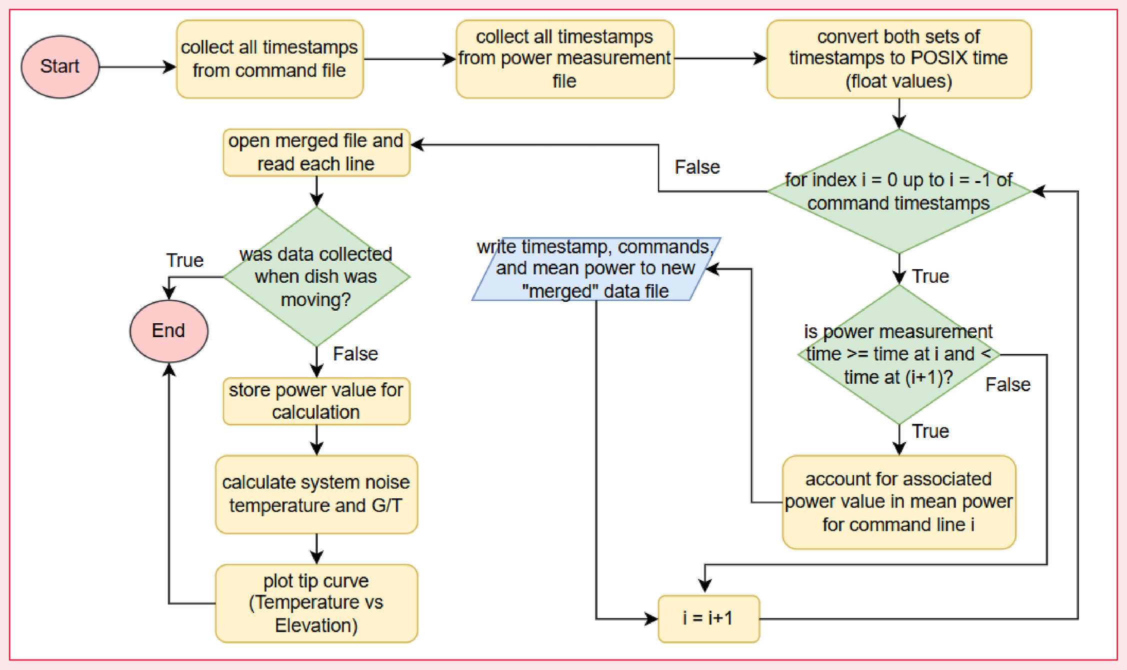
G/T Measurement Procedure Diagram



Command Software Algorithm



Parsing Software Algorithm



References

[1] Sanchez Net, M., Wyatt, J., Johnston, M., Castano, R., Townes, S. A., Lazio, T. J. W., Malphrus, B. K., Kruth, J. A., Hart, C., & Mattle, E. (2022, June). *Enabling a Larger Deep Space Mission Suite: A Deep Space Network Queuing Antenna for Demand Access. 2022 SpaceOps Workshop*. Mountain View; California (NASA Ames Research Center).

[2] Zelle, J. M. (2017). *Python programming: An Introduction to Computer Science* (3rd ed). Franklin, Beedle & Associates Inc.

[3] NASA Jet Propulsion Laboratory. (2017, May 3). DSN Telecommunications Link Design Handbook. Pasadena; California Institute of Technology.

[4] Walter, E. (2023, August 16). Fundamentals of Gain Over System Noise Temperature. personal.

Phase III Testing: April 21, 2024

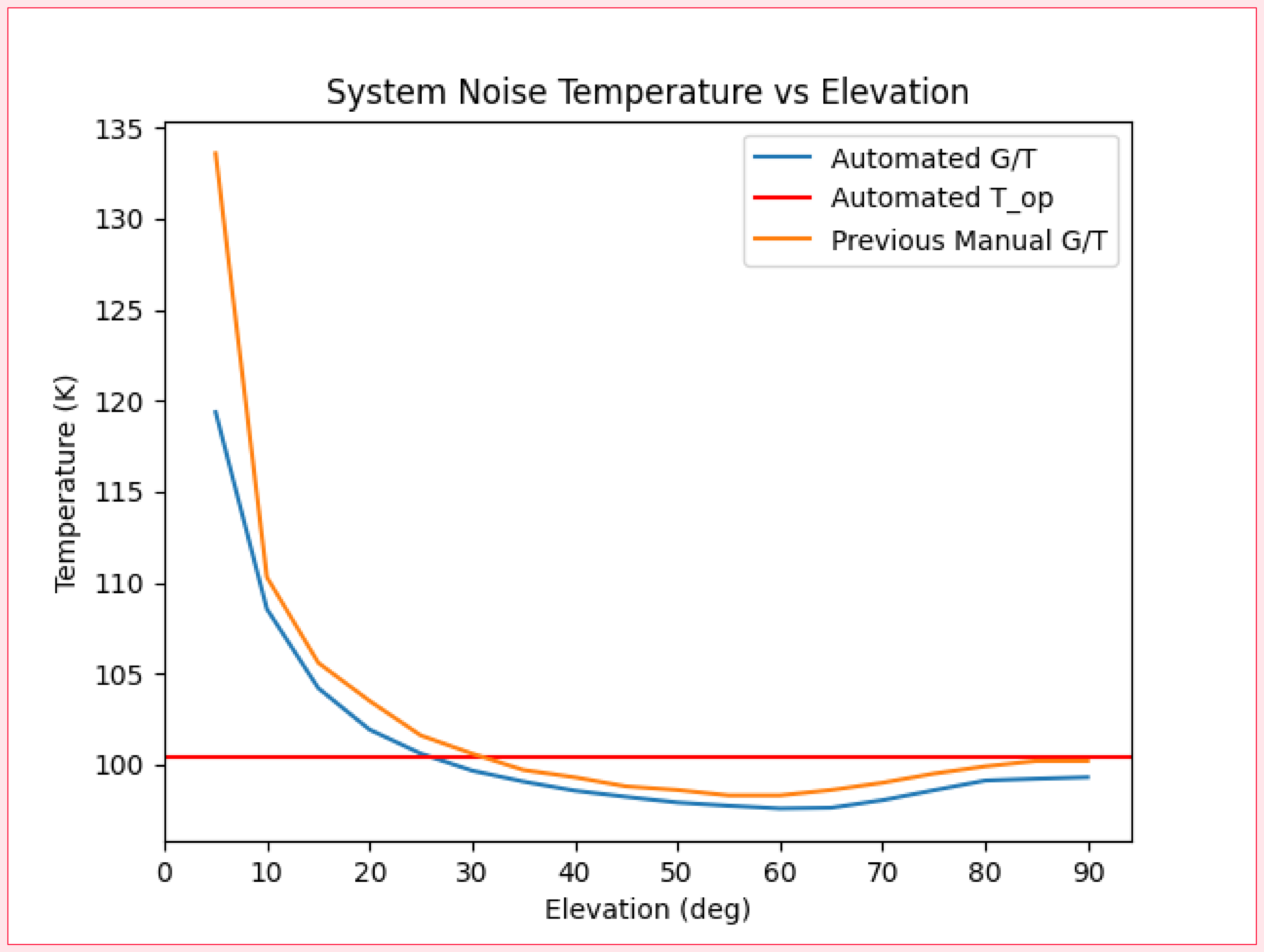
Automated G/T Procedure

Test Setup, Results, and Next Steps

During Phase III of testing, the automation software for both the command file generation and data parsing and calculation were tested. The hardware setup consisted of a 25dB attenuator and an 8184D Agilent power head connected to the ground station's DCD. On the other end of the power head was the calibrated Agilent E4418D EPM power meter. A GPIB attached the meter to a USB and to the computer housing power data collection software. On a separate computer was the STK scenario. From this, the AER report was generated. The report was then read by the command software on the same computer to create a pointing file. The pointing file was downloaded to DSS-17's computer. Shortly before the automated track, the data collection code was started. Once the dish completed the track, data collection ended, and the file of power values was sent to the computer housing the parsing software to begin calculating G/T values and graph the tip curve at 119 degrees azimuth.

Phase III progressed successfully. The dish successfully read in and proceeded with the commands of the pointing file, and the tip curve generated was graphically and numerically similar to those of previous G/T tests. The small uptick in temperature at the higher elevations is likely the result of signal spillover as the dish approaches a 90-degree elevation with respect to the hot ground. This uptick is observed in previous G/T procedures. Additionally, the automated test procedure yields significantly smaller pointing errors when comparing the commanded and actual pointing of the dish for every second of the track. In all three phases of testing, the mean error was reduced by anywhere from 1 to 4 degrees of magnitude as compared to the pointing error during manual G/Ts. Continued tests will be made to verify and validate the automated procedure.

The next steps of this project include using the software to get a reading at the S-band frequency and debugging and revising the code to make it more user-friendly. Most excitingly, MSU is currently upgrading DSS-17 from a prime-focus antenna to a Cassegrain-focus, so this newly automated procedure will allow us to see how the new focus affects our G/T measurements.



$P_{ON} = -30.752106537530267$ dBm — mean power value on blackbody
$P_{OFF} = -35.21221231864563$ dBm — mean power value on cold sky
$G = 62.7$ dBi — theoretical X-band gain of DSS-17

Given the equation: $$T_{op} = \frac{180}{10^{(P_{ON}-P_{OFF})/10}-1}\,[\mathrm{K}] \rightarrow \boldsymbol{T_{op}} = \mathbf{100.41214387247757\ K}$$

Given the equation: $$\frac{G}{T} = G - 10\log(T_{op})\,[\frac{dB}{K}] \rightarrow \boldsymbol{\frac{G}{T}} = \mathbf{42.7\ dB/K}$$

	Azimuth	Elevation
Mean Pointing Error	0.000065551	0.000104934
Maximum Pointing Error	0.001089791	0.018570583