# Determination of
# Earth Station Antenna G/T
# Using the Sun or the Moon as an RF Source

For Small Aperture (≤ 5.0m) Parabolic Earth Station Antenna Systems Operating from L to Ka-Band

Presenter: Michael Morgan

# What is G/T?

- Figure of Merit: Antenna Gain to Noise Temperature, typically measured in decibels per Kelvin (dB/K)
- Ability of an antenna to receive the target frequency in the presence of noise
- Measurement requires an RF source of known frequency and transmit power.  Most common RF source used is the Sun

# How is G/T Calculated?

- The difference between the RF power received by the RF source and by cold sky is determined($P_{delta}$). Due to precision limitations of spectrum analyzers, a minimum $P_{delta}$ value of 0.5 dBm is required
- $P_{delta}$ is then converted to a linear value ($y$ value)
- Flux Density of the RF source reaching the surface of the Earth is determined
- Additional correction factors for Source Size (Beam Size) and Atmospheric Attenuation are calculated
- These values are then used to calculate a G/T for the antenna

# Why is G/T Measured using the Sun?

- Large difference between received RF power from the Sun and cold sky ($P_{delta}$) on almost any sized system.

- Solar Flux Density is measured throughout the day at Solar Observatories around the Earth.  Value does not need to be calculated

http://services.swpc.noaa.gov/text/current-space-weather-indices.txt

- The Sun's location is easily calculated and normally visible for long periods of time

# Empirical Formula (Sun)

$$\frac{G}{T} = 10\log_{10}\left[\frac{8\pi k(y-1)}{S_0\lambda^2 C\alpha}\right] \quad \left[\frac{dB}{K}\right]$$

where,

$\frac{G}{T}$ Calculated $\frac{G}{T}$ of the antenna system in $\frac{dB}{K}$

$k$ Boltzmann Constant, $1.38 * 10^{-23} \frac{W}{Hz*K}$

$y$ Difference of source power density to cold sky power density, no units

$S_0$ Solar Flux Density, expressed in Solar Flux Units (SFU) $10^{-22} \frac{W}{m^2*Hz}$

$\lambda$ Measurement Frequency Wavelength in meters

$C$ Beam Correction Factor, no units

$\alpha$ Atmospheric Attenuation at elevation angle, no units

# Alternative Source (Moon)

- The Moon is also a source of RF emissions which can be used to calculate G/T
- Lunar Flux Density is calculated at the testing location
- In some cases, such as geographical locations where the Sun is not visible for long periods of time (i.e. extreme latitudes), the Moon is an optimal choice as an RF source

# Empirical Formula (Moon)

$$\frac{G}{T} = 10\log_{10}\left[\frac{8\pi k(y-1)}{L_0\lambda^2 C\alpha}\right] \quad \left[\frac{dB}{K}\right]$$

where,

$L_0$ Lunar Flux Density, expressed in Solar Flux Units (SFU) $10^{-22}\ \frac{W}{m^2 * Hz}$

Algorithms for solving for the y value, wavelength, beam correction factor, and atmospheric attenuation are given in the associated paper

# Calculating Lunar Flux Density

$$L_0 = 7.349 f^2 T d^2$$

where

$L_0$ Lunar Flux Density in Jansky's, $10^{-26} \frac{W}{m^2 * Hz}$

$f$ Measurement Frequency in GHz

$T$ Average Lunar Brightness Temperature in Kelvin

$d$ Angular Diameter of the Moon in Degrees

- Calculating an exact Lunar Brightness Temperature is extremely extensive, therefore an average Lunar Brightness Temperature is used. This introduces a small error into the resulting G/T value

# Average Lunar Brightness Temperature

$$T = T_0\left[1 - \left(\frac{T_1}{T_0}\right)\cos(\phi - \psi)\right]$$

where

| | |
|---|---|
| $T$ | Average Lunar Brightness Temperature in Kelvin |
| $T_0$ | $207.7 + \frac{24.43}{f}$ |
| $\frac{T_1}{T_0}$ | $0.004212 f^{1.224}$ |
| $f$ | Measurement Frequency in GHz |
| $\phi$ | Lunar Phase Angle in Degrees (0° at New Moon) |
| $\psi$ | Lunar Phase Lag in Degrees = $\frac{43.83}{1+0.0109f}$ |

Lunar Phase Angle Equations are given in the associated paper

# Example Calculation

| Test Antenna System | |
|---|---|
| **Manufacturer** | Orbital Systems, Ltd. |
| **Model** | 3.0TSXS2-3.7m |
| **Reflector Diameter** | 3.66 m (12 feet) |
| **Frequency** | 8200.0 MHz (X-band) |
| **Date** | 2018-05-22 |
| **Time** | 21-50 UTC |
| **Weather** | Clear Sky |

| Spectrum Analyzer Settings | |
|---|---|
| **Frequency** | 1250 MHz IF (8200 MHz RF) |
| **Span** | 2 MHz |
| **Resolution Bandwidth** | 1 MHz |
| **Video Bandwidth** | 100 Hz |
| **Scale** | 2 dB/division |
| **Amplitude** | 1 division below top of scale |
| **Averaging** | On (100 samples) |

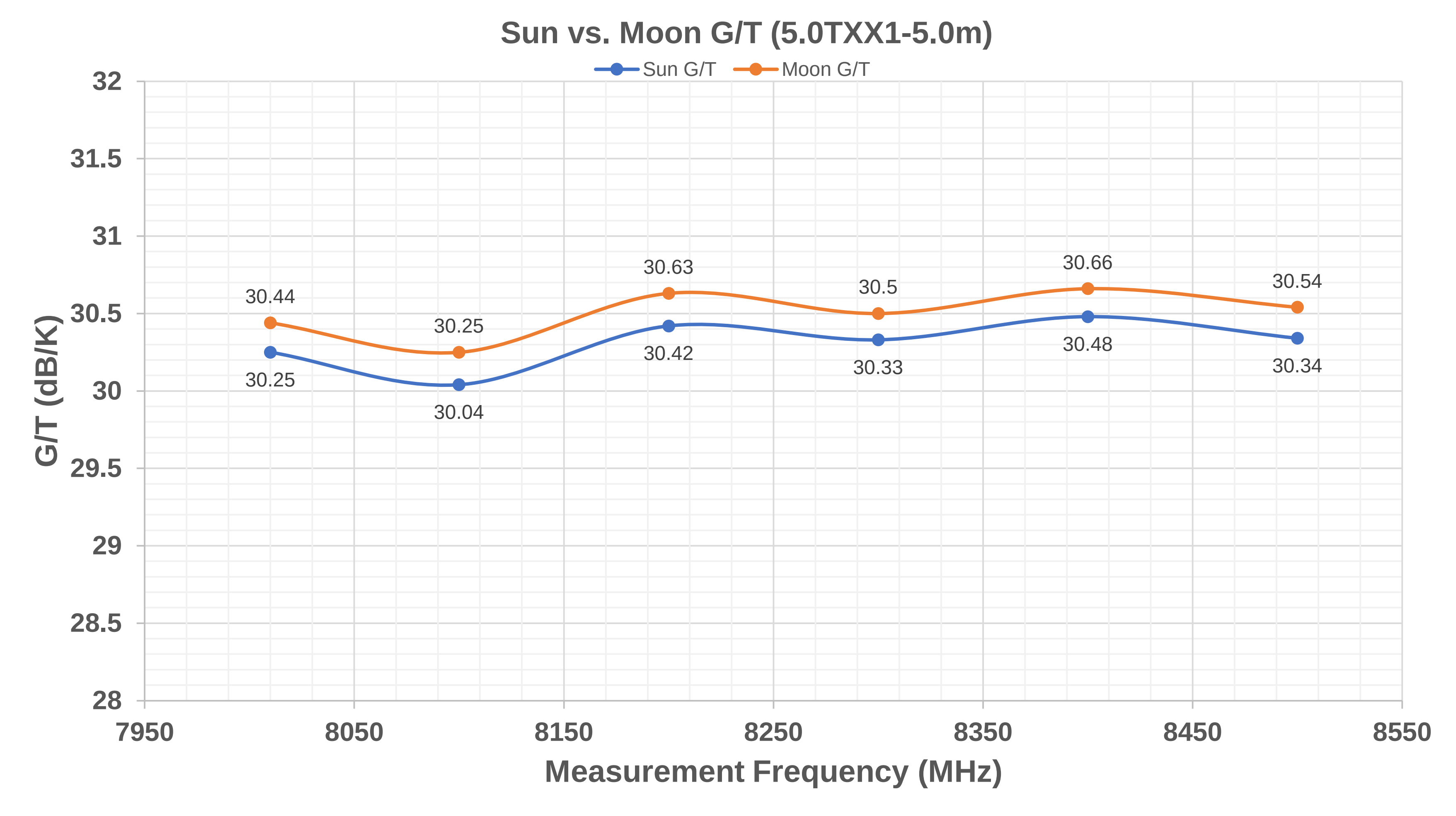
# Calculations: Sun & Moon

| G/T Measurement, RF Source: Sun | | |
|---|---|---|
| **Measurement** | Unit | Result |
| **Frequency** | MHz | 8200.0 |
| **Elevation Angle** | degrees | 41.22 |
| **Flux Measurement Freq. 1** | MHz | 4995.0 |
| **Flux Measurement 1** | SFU | 109.0 |
| **Flux Measurement Freq. 2** | MHz | 8800.0 |
| **Flux Measurement 2** | SFU | 235.0 |
| **Flux Interpolation Exponent** | No Units | 0.125 |
| **Solar Flux Density** | SFU | 213.532 |
| **Wavelength** | meters | 0.037 |
| **Beamwidth** | degrees | 0.672 |
| **Zenith Attenuation** | dB | 0.046 |
| **Atmospheric Attenuation** | dB | 0.069 |
| **Sun Optical HPBW** | degrees | 0.525 |
| **Sun Effective RF Diameter** | degrees | 0.573 |
| **Beam Correction Factor** | No Units | 0.786 |
| $P_{sun}$ | dBm | -51.45 |
| $P_{csky}$ | dBm | -68.12 |
| $P_{delta}$ | dBm | 16.67 |
| $y$ | No Units | 46.42 |
| | | |
| **G/T** | **dB/K** | **28.53** |

| G/T Measurement, RF Source: Moon | | |
|---|---|---|
| **Measurement** | Unit | Result |
| **Frequency** | MHz | 8200.0 |
| **Elevation Angle** | degrees | 36.48 |
| **Lunar Ground Station Dist.** | km | 371963.3 |
| **Lunar Semidiameter** | degrees | 0.268 |
| **Lunar Angular Diameter** | degrees | 0.540 |
| **Surface Radio Temperature** | K | 201.740 |
| **Lunar Phase Angle** | degrees | 80.160 |
| **Lunar Illumination** | % | 58.550 |
| **Wavelength** | meters | 0.037 |
| **Beamwidth** | degrees | 0.67 |
| **Lunar Flux Density** | SFU | 2.86 |
| **Zenith Attenuation** | dB | 0.047 |
| **Atmospheric Attenuation** | dB | 0.080 |
| **Beam Correction Factor** | No Units | 0.81 |
| $P_{moon}$ | dBm | -65.87 |
| $P_{csky}$ | dBm | -68.11 |
| $P_{delta}$ | dBm | 2.24 |
| $y$ | No Units | 1.67 |
| | | |
| **G/T** | **dB/K** | **28.87** |

**Percentage Difference: 1.18 %**

# Comparison: Sun & Moon




**Average Percentage Difference: 0.64 %**

# Moon G/T Limitations

- The Moon's location and flux density can be mathematically intensive to calculate relative to the Sun
- Smaller aperture antenna's, especially when operated at lower frequencies, may not have enough $P_{delta}$ for a useful result

| | Frequency Band | | | | | |
|---|---|---|---|---|---|---|
| Reflector Size | L | S | C | X | Ku | Ka |
| 1.5 m (5 ft.) | X | X | X | | ✓ | ✓ |
| 1.8 m (6 ft.) | X | X | X | | ✓ | ✓ |
| 2.4 m (8 ft.) | X | X | | ✓ | ✓ | ✓ |
| 3.0 m (10 ft.) | X | | ✓ | ✓ | ✓ | ✓ |
| 3.7 m (12 ft.) | | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.0 m (16.4 ft.) | | ✓ | ✓ | ✓ | ✓ | ✓ |

Orbital Systems

# Conclusions

- My empirical evidence of Moon based G/T calculations have results within a few percent of the G/T measured using the Sun
- Algorithms can easily be implemented in software (Java, C++, etc.). The Sun algorithm can easily be implemented in a spreadsheet
- A Moon based G/T calculation could be considered as “more accurate” than a Sun based calculation due to the greater degree of certainty in a Lunar Flux Density calculation versus a Solar Flux Measurement (not made at the test antenna’s location)
- Some of the variability in G/T calculations (especially Sun based) can be reduced by averaging calculations over multiple days

Orbital Systems

TRACKING OUR WORLD

# Questions?

## Come see us at Booth 176 & 177