Atmospheric-Induced Effects Observed on Deep Space Ka-band Carrier Signals

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Ka-band For Deep Space Missions

- Ka-band is planned to be a telecommunications link frequency for upcoming deep-space missions
  - Mars Reconnaissance Orbiter
  - Kepler
  - Mars Telesat Orbiter
  - Jupiter Icy Moons Orbiter
  - Solar Probe
- Previous Studies Have Been Conducted using Ka-band on Deep Space Missions
  - Mars Observer
  - Mars Global Surveyor
  - Deep Space 1
  - Cassini
- Recently Studies have been conducted using Cassini's Ka-band carrier

Ka-band For Deep Space Missions

- Ka-band offers increased advantage over X-band as a telecommunications link frequency
  - In theory about 11 dB advantage
- However, atmospheric liquid and gaseous water (as well as reduced antenna efficiency) contribute to loss and fluctuations in Ka-band signals
  - In practice, expect about 6 to 8 dB advantage over X-band
- It becomes important to characterize and understand propagation effects at Ka-band
  - Have demonstrated about 5 dB advantage over X-band using Ka-band
- Such knowledge is useful for developing optimum telemetry return strategies using Ka-band
- Significant amount of work has been performed to understand these effects by the Earth orbiting satellite community
- Such atmospheric-induced effects on signal power include
  - Rain fades
  - Scintillation
  - Increased thermal noise

Recent Ka-band Deep Space Mission Activity

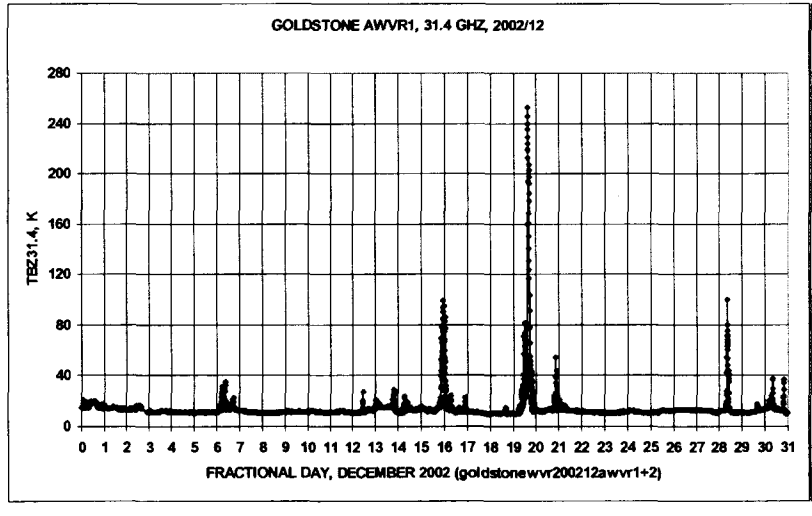
- Cassini Gravitational Wave Experiment (GWE) was conducted between December 6, 2002 and January 14, 2003
- Prime antenna equipped with Ka-band used for Cassini GWE is located in Goldstone, California
- Experiment was conducted during opposition when charged particle effects are expected to be minimal
- Experiment was conducted in late autumn and winter and at night; Goldstone desert climate expected to be cold and dry
  - Minimal atmospheric effects expected on Ka-band signal links
- A full complement of troposphere media calibration equipment was gathering data used to calibrate out atmospheric effects from GWE data.
  - Water Vapor Radiometers – co-aligned along signal path of BWG
  - Microwave Temperature Profilers
  - Meteorological Sensors

Signal Amplitude

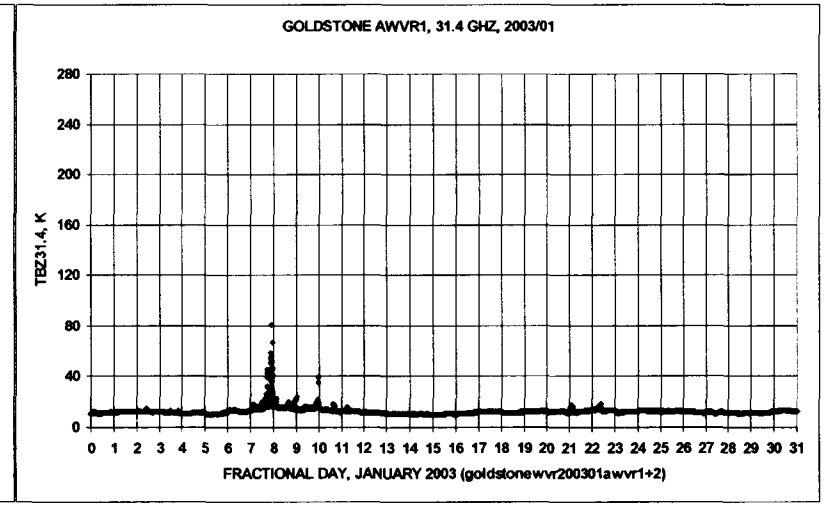
- Amplitude (or SNR) extracted from open-loop and closed-loop receivers
- About 438 hours of Goldstone Ka-band signal amplitude (and phase) data were acquired during the 40 day campaign
- Very few passes revealed any signatures that could be attributed to weather
- 2002/349 – few periods of minor "fading" up to 5 dB
  - Correlated with cloudy weather and increased activity revealed by WVR data.
  - Probably due to mechanical response of system exacerbated by the weather
- 2002-363 – only example of "classic" rain fade
  - Reached a maximum value of 6 dB in SNR
  - Exceeded 1 dB over 2 hours in SNR
  - Exceeded 1 dB over 1 hour in attenuation
  - Signature of fade feature is in good agreement with fade reconstructed from combined thermal noise and attenuation contributions predicted from WVR data.
- 2002/365 – few fades
  - Used as example pass to evaluate scintillation

WVR 31.4 GHz Zenith Brightness Temperature

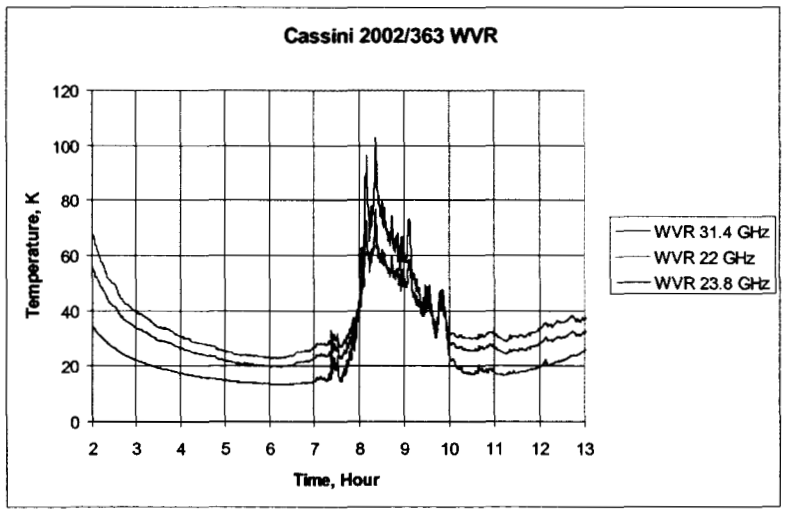
December 2002

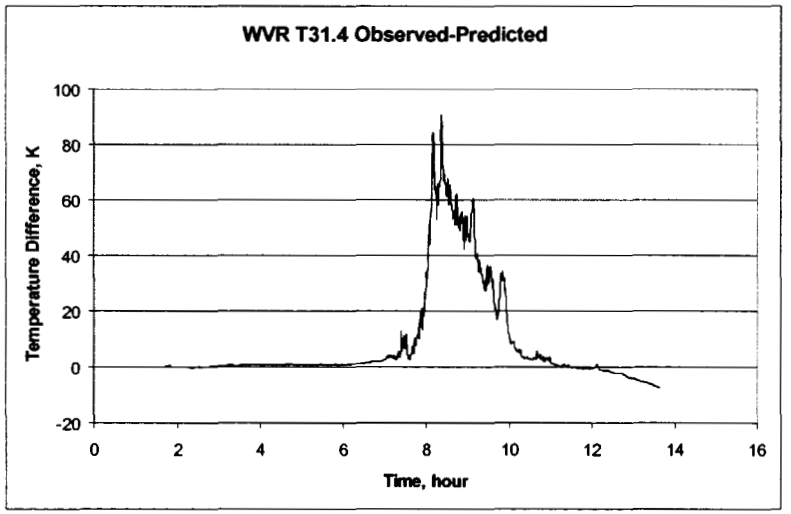


January 2003

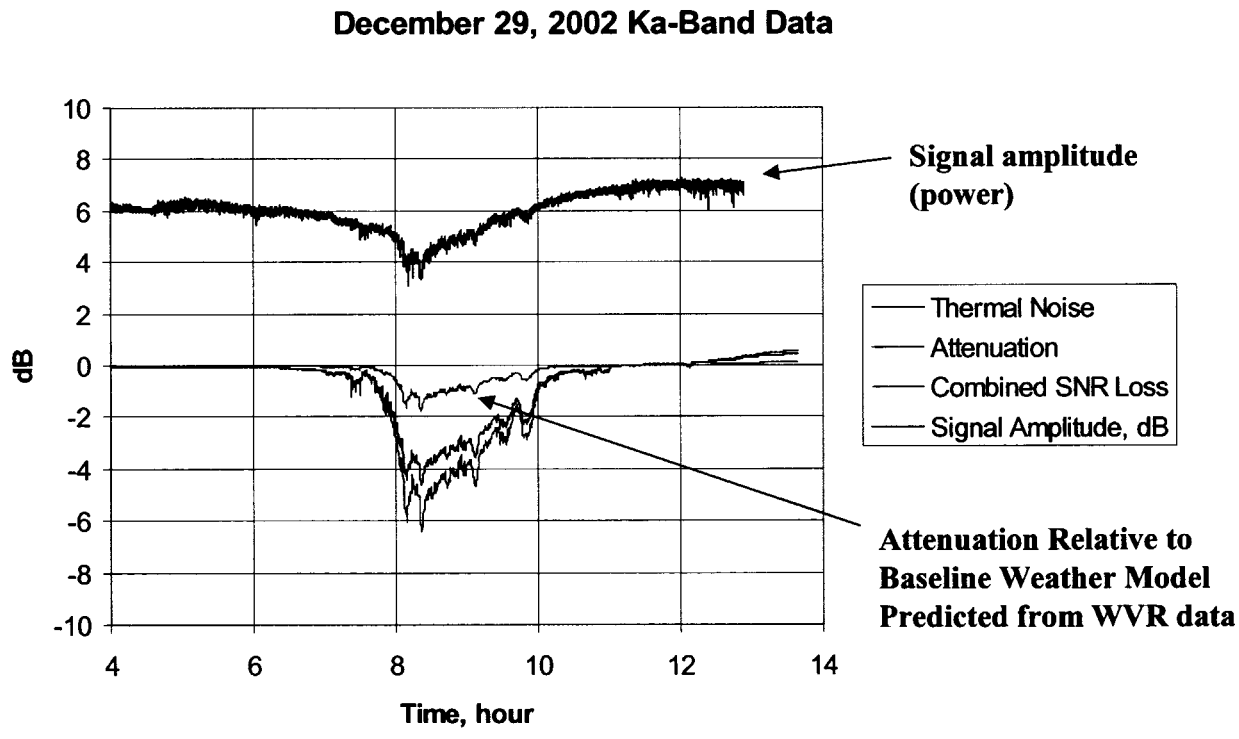


Cassini GWE 2002/363 WVR Brightness Temperatures Measured Along Signal Path

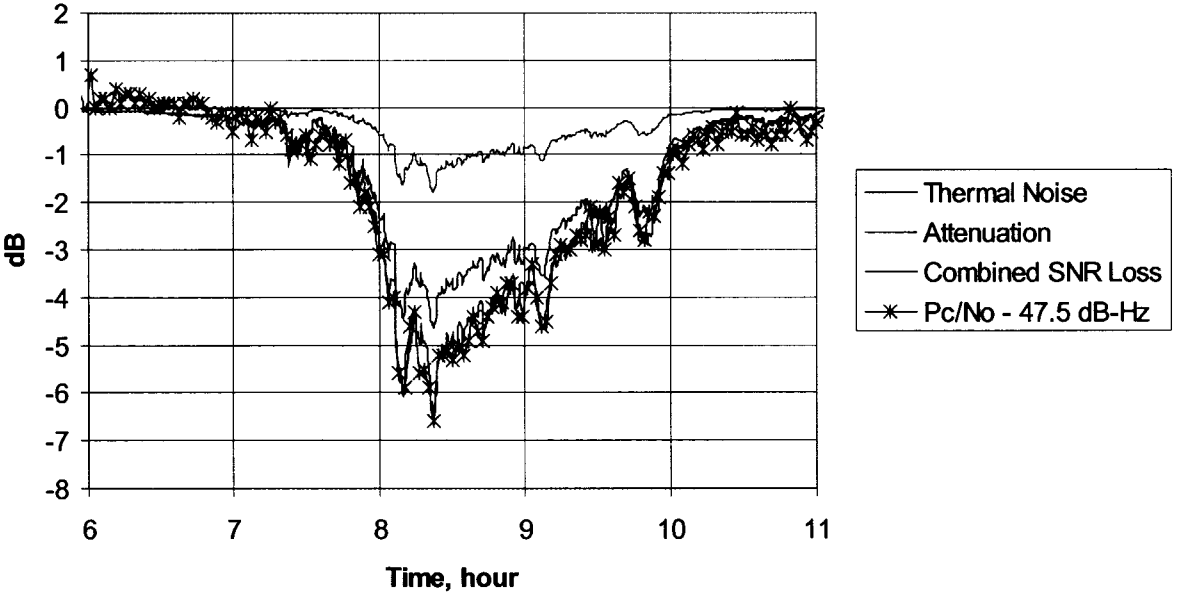




Cassini 2002/363 (December 29) Signal Amplitude (Power) Measured and Predicted



Cassini 2002/363 (December 29) Signal SNR Measured from DTT and Predicted from co-aligned WVR



Model

- Parameters

$T_{phys} = 280$ K	physical temperature of atmosphere (model)
$\tau = 0.0365$	atmosphere optical depth (model)
$T_{equip} = 35$K	contributions to Tsys of antenna and equipment at DSS-25 (model)
$T_{cos} = 2$ K	cosmic background at 32 GHz (model)
$A = 1/\sin(elev)$	number of air masses at elevation angle

$$T_{sys\text{-}mod} = T_{cos} * e^{-\tau A} + T_{phys}(1 - e^{-\tau A}) + T_{equip}$$
$$T_{sys\text{-}wvr} = T_{wvr} + 0.3 + T_{equip}$$

$$T_{atm\text{-}mod} = T_{phys}(1 - e^{-\tau A})$$
$$T_{atm\text{-}wvr} = T_{wvr} + 0.3 - T_{cos}$$

- Attenuation

$$\text{Att (dB)} = 10 \log (1 - T_{atm}/T_{phys})$$
$$\text{dAtt} = 10 \log (1 - T_{atm\text{-}wvr}/T_{phys}) - 10 \log (1 - T_{atm\text{-}mod}/T_{phys})$$

- Thermal Noise

$$\text{dTN} = 10 \log (T_{sys\text{-}wvr}/ T_{sys\text{-}mod})$$

- Total SNR Degradation

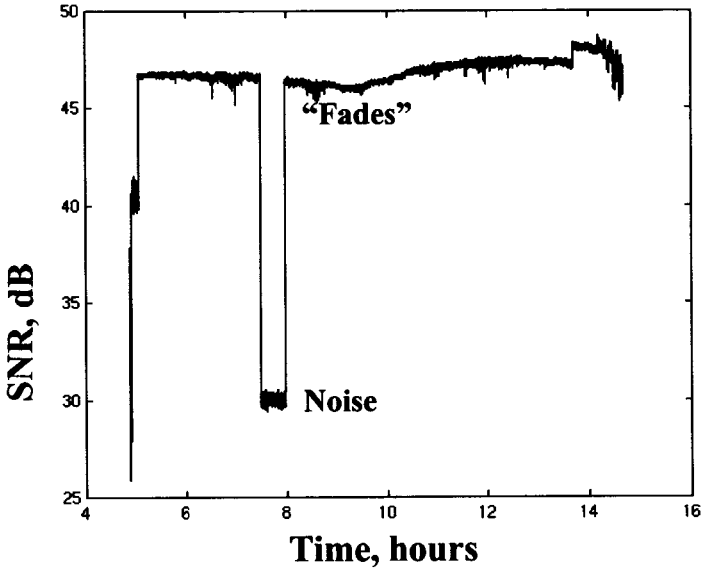
dAtt + dTN

Attenuation "Fade" Statistics

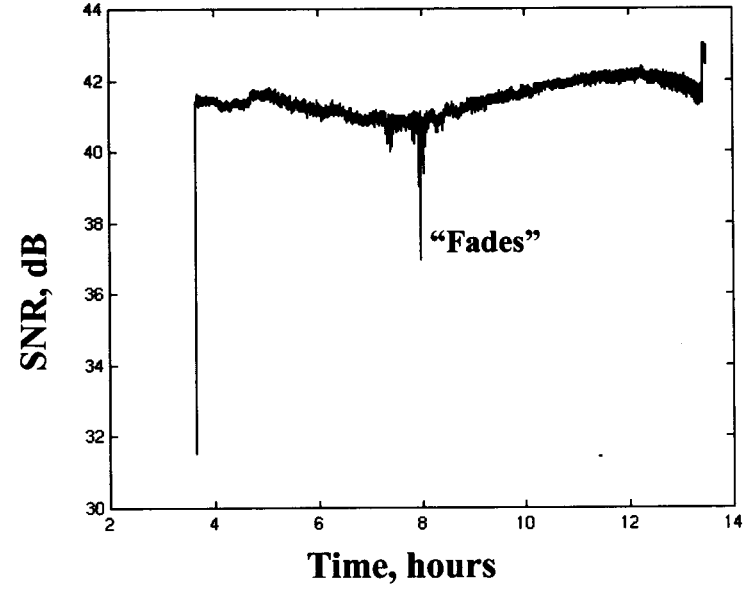
- Only Cassini GWE pass observed to have significant fading attributed to weather was 2002/363 (December 29, 2002)
- Other periods with significant attenuation predicted from WVR data fell outside Cassini GWE signal acquisition periods
- 1 dB attenuation exceeded in about 1 hour over 438 hours of acquired signal amplitude data
  - Fade exceeded 0.22% of time, includes January (438 hours)
  - Fade exceeded 0.37% of time for December only (273.5 hours)
- AWVR2 complete data set acquired during December 2002
  - A 1 dB fade would be exceeded 0.7% of the time
- Overall Goldstone WVR data base used for DSN 810-5 Document
  - December - 1 dB fade would be exceeded 0.45% of the time
  - January - 1 dB fade would be exceeded 0.53% of the time

Examples of SNR with Short-term Signal Variations

2002/349 DSS-25 X up Ka down



2002/365 DSS-25 X up Ka down



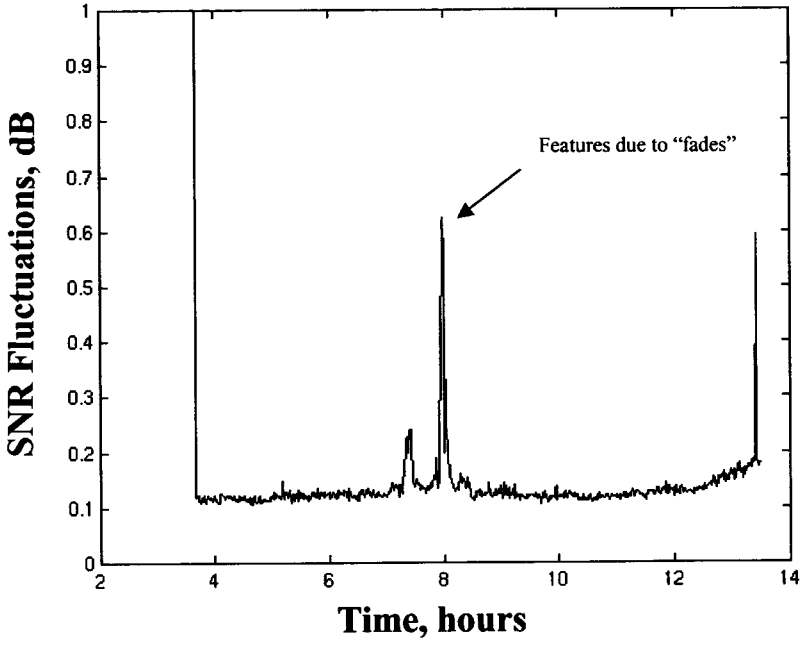
For these passes, these short period "fades" appear to be correlated with mechanical pointing control response to the weather.

Signal Amplitude: Scintillation

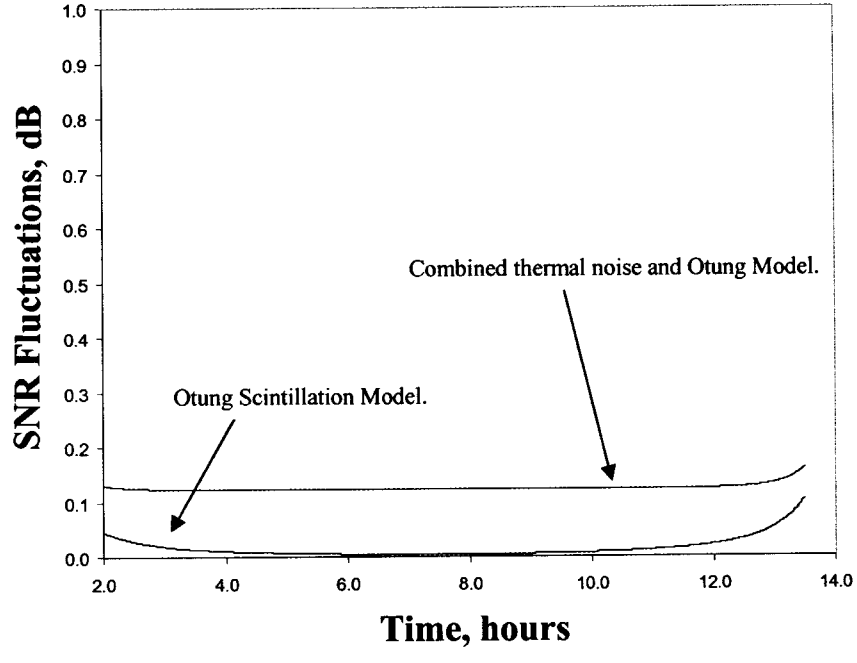
- Measured scintillation computed by taking a moving average using high pass filtering at a suitable cutoff frequency to remove long period trends.
- Samples were presumed to perform low pass filtering to remove very rapid fluctuations attributed to other noise sources.
- Even during periods of turbulent weather along signal path, effect of scintillation was relatively small.
- Level of scintillation appears to be minimal and lies below thermal noise level (0.12 dB) for most of the pass until effect can be detected at low elevation angles
- **Amplitude scintillation does not dominate fluctuations in signal amplitude**
- **Data from other spacecraft missions confirm this.**

Signal Amplitude: Scintillation

2002/365 - Measured Noise on Pc/No



2002/365 – Predicted Noise on Pc/No



Otung, I., "Prediction of Troposphere Amplitude Scintillation on a Satellite Link", IEEE Trans on Ant. & Prop. Vol. 44, No. 12, December 1996.

Conclusion

- Troposphere Effects on Ka-band Carrier Signals were examined by analyzing data from "recently" conducted Cassini GWE
- Amplitude fades observed but were rare given Goldstone winter nighttime dry climatic conditions
- Scintillation was below detectable levels for most of the experiment and considered negligible
- Such data is useful to study effects on Ka-band signals for planning for deep space missions
- A more rigorous study of tropospheric effects on Ka-band signals will be conducted with upcoming MRO mission which has a full Ka-band link
  - Telemetry Experiments
  - Navigation Experiments
  - Propagation Experiments

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