PROPAGATION EFFECTS OF IMPORTANCE TO THE NASA/JPL DEEP SPACE NETWORK (DSN)

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DSN ANTENNAS

Pictures of antennas and information about the Deep Space Network (DSN) are available at http://www.jpl.nasa.gov (Site Directory - Deep Space Network)

The DSN operates a worldwide distribution of large ground-based antennas operating at S-band (2.3 GHz), X-band (8.4 GHz), and Ka-band (32 GHz):

Goldstone, California:
- (1) 70-m @ S,X-bands
- (1) 34-m HEF @ S,X-bands
- (2) 34-m BWG @ S,X-bands
- (1) 34-m BWG @ S,X,Ka-bands (supports Ka-band on Cassini and DS-1)
- (1) 26-m X-Y @ S-band

Canberra, Australia:
- (1) 70-m @ S,X-bands
- (1) 34-m HEF @ S,X-bands
- (1) 34-m BWG @ S,X-bands
- (1) 26-m X-Y @ S-band

Madrid, Spain:
- (1) 70-m @ S,X-bands
- (1) 34-m HEF @ S,X-bands
- (1) 34-m BWG @ S,X-bands
- (1) 26-m X-Y @ S-band

Notes:
(1) The feeds on the 70-m, HEF (high-efficiency), and X-Y antennas are located in feedcones above the main reflector surface.
(2) The feeds on the BWG (beam-waveguide) antennas are located in a subterranean "pedestal room."
(3) Investigations are underway to implement Ka-band on the 70-m and HEF antennas.
(4) Additional overseas BWG antennas are to be added in the future.

DEEP SPACE TELECOM LINK BASICS

The data rate a telecom link can sustain is proportional to received Eb/No (energy per bit/system noise temperature), which is a function of spacecraft range, EIRP, pointing, atmospheric loss, other losses, and system noise temperature.

Eb/No is proportional to ground antenna G-effective/T-op (ratio), where

Geffective (dB) = effective antenna gain
= vacuum antenna gain (dBi) - atmosphere loss (dB)

Top (K) = system operating noise temperature
= Top,vacuum (K) + Tatm (K)

The reduction of G/T with respect to a vacuum atmosphere condition is given by

Δ(G/T) w.r.t. vacuum = -Aatm (dB) - 10*log[(Top,vac + Tatm)/(Top,vac)]

Typical Top,vacuum (includes cosmic, I^2R losses, spillover, scatter, T-LNA, T-feed):
- S-band (2.3 GHz): 13.4 K (9.8 K on Australia 70-m to support Galileo)
- X-band (8.4 GHz): 18.4 K (to be lowered to 15K to support Cassini)
- Ka-band (32 GHz): 37.1 K

Example: If Top,vac is a low number (e.g., 20 K), then small atmosphere losses (e.g., 0.3 dB, which gives a Tatm of about 18.4 K) result in a Δ(G/T) almost solely due to the noise temperature term. In this example, the 0.3 dB atmosphere loss causes a 0.3 + 2.8 = 3.1 dB G/T decrease relative to a vacuum G/T.

DSN PROPAGATION REGION OF INTEREST

The figure below shows propagation regions of interest for Earth satellite telecommunications where there is sufficient link margin to overcome atmosphere attenuations in excess of 5 to 20 dB. In contrast, the region of interest for deep-space communications is limited to atmosphere attenuations below about 2 dB, which limits link availability to below 90% at low elevation angles, even for relatively benign locations such as Las Cruces, New Mexico (shown below).

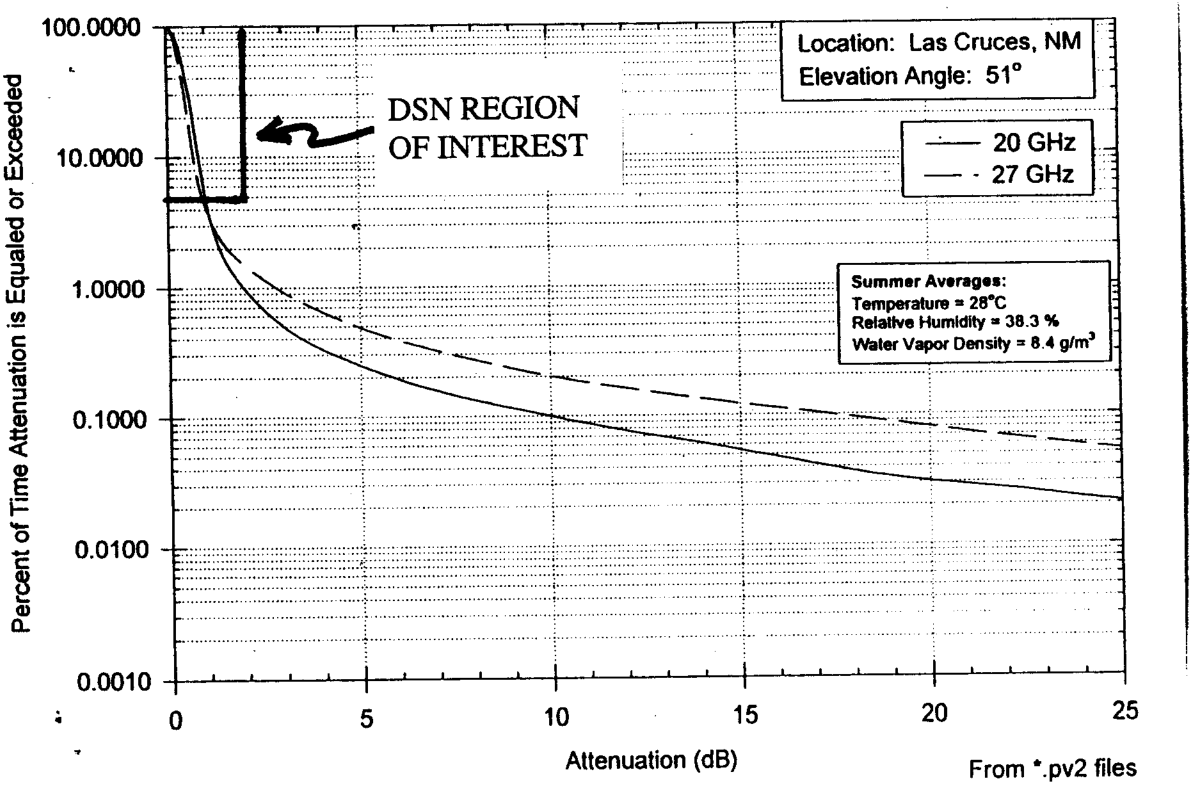

Figure 1. Attenuation with Respect to Free Space for Summer (June, July, August) 1994-1998

The above figure appeared in *Proceedings of the Eleventh Advanced Communications Technology Satellite Propagation Studies Workshop (APSW XI)*, JPL Publication 98-13, p. 156.

Ka-BAND WEATHER EFFECTS MODELS AND EXAMPLES

EFFECT OF INCREASING ATMOSPHERE LOSS FOR LOW-NOISE SYSTEMS

The following spreadsheet example shows the effect on G/T degradation of small changes in atmosphere attenuation for low-noise systems such as the DSN BWG Ka-band antennas.

The vacuum system noise temperature at zenith is 37.1 K. Assume that a telecom link is designed to have a 3-dB margin under some nominal condition where the atmosphere loss is 0.3 dB and its corresponding noise temperature contribution is 18.36 K. The degradation relative to a vacuum condition is shown as 2.05 dB. If, however, the atmosphere attenuation increases to 1.0 dB, the degradation relative to vacuum has now increased to 5.02 dB and the 3-dB margin has disappeared.

Table 1. Effect of Increasing Atmosphere Loss on Telecom Margin

A-atm (dB)	L-atm	T-atm (K)	T-op (K)	delta-G/T (dB) w.r.t. vacuum	delta-G/T (dB) w.r.t. baseline
0.0	1.000	0.00	37.10	0.00	
0.1	1.023	6.26	43.36	-0.78	
0.2	1.047	12.38	49.48	-1.45	
0.3	1.072	18.36	55.46	-2.05	0
0.4	1.096	24.20	61.30	-2.58	-0.53
0.5	1.122	29.91	67.01	-3.07	-1.02
1.0	1.259	56.56	93.66	-5.02	-2.98
1.5	1.413	80.31	117.41	-6.50	-4.46
2.0	1.585	101.49	138.59	-7.72	-5.68
3.0	1.995	137.17	174.27	-9.72	-7.67
5.0	3.162	188.04	225.14	-12.83	-10.79

Note: Tvac = 37.1 K

EXISTING GOLDSTONE Ka-BAND ATMOSPHERE ATTENUATION MODEL

In the table below, the existing weather effects model for Goldstone is given in the first row as the zenith atmosphere attenuation under various weather cumulative distributions. As an example, it is shown that, at zenith, the attenuation is 0.202 dB or less, 90% of the time. Conversely, this value is exceeded only 10% of the time. The elevation angle modeling is made as 1/sin(elev).

Table 2. Existing Attenuation Model for Goldstone at Ka-band.

	CD>>	0.00	0.25	0.50	0.80	0.90	0.95	0.98
elevation	airmass	************************************A-atm (dB)**						
90	1.000	0.083	0.115	0.132	0.165	0.202	0.269	0.386
60	1.155	0.096	0.133	0.153	0.191	0.234	0.310	0.446
30	2.000	0.166	0.230	0.265	0.331	0.405	0.538	0.772
20	2.924	0.243	0.336	0.387	0.484	0.591	0.786	1.129
15	3.864	0.321	0.444	0.512	0.639	0.782	1.039	1.491
12	4.810	0.399	0.553	0.637	0.796	0.973	1.293	1.857
10	5.759	0.478	0.662	0.762	0.953	1.165	1.548	2.223
8	7.185	0.596	0.826	0.951	1.188	1.454	1.931	2.774
6	9.567	0.794	1.100	1.267	1.582	1.935	2.572	3.693

EXISTING GOLDSTONE ATMOSPHERE NOISE TEMPERATURE MODEL

The table below shows the atmosphere noise contributions corresponding to the attenuation values given in the previous table. A rule of thumb is that for attenuations in the 0-1 dB range, the corresponding noise temperatures vary linearly from 0 to 60 K.

Table 3. Existing Noise Temperature Model for Goldstone at Ka-band.

	CD>>	0.00	0.25	0.50	0.80	0.90	0.95	0.98
elevation	airmass	******************************			T-atm (K)			******************************
90	1.000	5.21	7.19	8.26	10.28	12.52	16.50	23.39
60	1.155	6.00	8.28	9.51	11.83	14.40	18.97	26.82
30	2.000	10.31	14.18	16.27	20.17	24.46	32.02	44.79
20	2.924	14.95	20.49	23.45	28.98	35.01	45.52	62.93
15	3.864	19.57	26.74	30.56	37.63	45.30	58.49	79.93
12	4.810	24.15	32.89	37.51	46.03	55.20	70.80	95.66
10	5.759	28.66	38.89	44.28	54.16	64.70	82.45	110.17
8	7.185	35.29	47.65	54.10	65.84	78.22	98.72	129.80
6	9.567	45.95	61.54	69.57	83.97	98.88	122.88	157.50

Ka-BAND Δ(G/T) RELATIVE TO VACUUM CONDITION

The following table shows telecom link G/T degradation due to atmosphere attenuation and noise temperature contributions above the vacuum condition, namely 0 dB atmosphere loss and 37.1 K system noise temperature. In the example below, assume a link has been designed with a 3-dB margin for 90% weather at 30-degrees elevation angle. In this case, the G/T degradation relative to vacuum is 2.60 dB (shown in the box). Those conditions which result in a further increase of 3-dB or more are shown highlighted. It is thus seen that operation of the link at worse weather and/or lower elevation angles is severely compromised. If, for example, operation at 6-degrees elevation angle (spacecraft rise and set conditions) is desired, the data rate will have to be reduced for weather conditions only slightly worse than 25% weather (average clear conditions).

Table 4. Telecom Link G/T Degradation due to Atmosphere Attenuation and Noise Temperature Contributions.

	CD>>	0.00	0.25	0.50	0.80	0.90	0.95	0.98
elevation	airmass	****************************delta-G/T (dB)**********************************						
90	1.000	0.65	0.88	1.01	1.23	1.46	1.87	2.51
60	1.155	0.75	1.01	1.14	1.39	1.66	2.10	2.81
30	2.000	1.23	1.64	1.84	2.22	2.60	3.24	4.21
20	2.924	1.71	2.25	2.51	2.99	3.48	4.26	5.44
15	3.864	2.16	2.80	3.12	3.68	4.25	5.15	6.48
12	4.810	2.58	3.31	3.67	4.30	4.93	5.93	7.39
10	5.759	2.96	3.78	4.17	4.86	5.55	6.63	8.21
8	7.185	3.50	4.41	4.86	5.62	6.38	7.57	9.30
6	9.567	4.29	5.35	5.85	6.72	7.58	8.92	10.89