7. Propagation Issues for Communication Between Earth and Mars

7.1 Free Space Loss Between Mars and Earth

When the Earth passes between Mars and the Sun (opposition), the minimum distance between the two planets is about 55×10^6 km. In contrast, when the two planets are on opposite sides of the Sun (superior conjunction), their maximum distance is close to 400×10^6 km.

Signal spread loss in free space is defined as L_{FS}

$$(L_{FS})_{dB} = 10log(\frac{4\pi d}{\lambda})^2 = 20log(\frac{4\pi d}{\lambda}) \tag{7-1}$$

Using this equation and the distances given above, we have calculated and listed the free space losses for various frequency bands in Table 7-1. Higher frequencies have larger losses, but mission designers can partially compensate for the losses by using higher antenna gain.

Table 7-1. Free Space Losses for Various Frequencies Between Mars and Earth

	Distance *d*	VHF Band (300MHz)	S Band (3 GHz)	X Band (10 GHz)	Ka-band (32 GHz)
Minimum Distance	55×10^6 km	~237 dB	~257 dB	~267 dB	~277 dB
Maximum Distance	400×10^6 km	~254 dB	~274 dB	~284 dB	~294 dB

The telecommunication system sets up the data transmission rate based on these losses. In order to maintain per-bit energies above the threshold, a lower data rate is usually used for a greater distance (that is, larger loss), while a higher data transmission rate is used for a lesser distance. This system is also set for a small margin (about 5 to 8 dB) for Earth weather degradation. Thus, when very bad weather occurs (heavy rain and clouds), the margin will be exceeded. Because both signal attenuation and background noise temperature increase, reception of high-transmission rate signals becomes difficult. This forces the system to change into a lower data transmission rate.

7.2 Combined Propagation Losses Under Normal and Worst Conditions

Because both Earth and Mars have ionospheres and atmospheres, radio waves suffer some losses in additional to the free space loss when they propagate through these media. At Earth, for 99% of the time, weather conditions are such that the total tropospheric attenuation for Ka-band is about 5 dB for vertical propagation. This loss includes gaseous absorption, rain and cloud scattering, etc. Among these losses, the dominant loss is due to rain scattering and absorption, about 3–4 dB under normal conditions. For the worst case, which occurs about 0.001% of the time, rain attenuation can be as large as 40–50 dB. Another large attenuation source is terrestrial dust storms. For extreme cases, a dust storm can cause a 50–60 dB attenuation at Ka-band.

Fortunately, these dust storms only occur in limited areas in the world, such as the Gobi Desert. Under normal conditions, these storms should only cause an attenuation of less than 3 dB. Also, dust storms are usually separate from rain storms. They almost never occur simultaneously at the same location. Thus, in the worst case (0.001% of the time), a Ka-band signal will suffer a 50 dB loss. A telecommunication system definitely cannot work at a normal transmission rate under this worst condition.

At Mars, the dominant attenuation factor is dust storms. For a worst case (large mass loading), attenuation can be 3 dB or higher at Ka-band. However, this type of storm rarely occurs. Dust storms mostly occur in the southern hemisphere during the spring and summer seasons. Under normal conditions, a storm can cause at most about a 1 dB loss.

At Mars no rain observation has been reported yet. Even though it is possible to have rain, the rain would be so light that it would not cause any significant attenuation to radio waves. It is estimated that total tropospheric losses, including gaseous attenuation, cloud, fog, and tropospheric scattering (scintillation and turbulence), etc., are about 0.4 dB at Ka-band. Thus, under normal conditions, the attenuation combined from a dust storm and the troposphere is about 1.4 to 2 dB for a vertically propagating wave (compared with about 5 dB at Earth). The total attenuation will be about 3.4 dB for the worst case. The attenuation parameters for various frequency bands are listed in Table 7-2.

The Martian ionosphere will have some absorption and scintillation effects on VHF wave transmission, just as the Earth's ionosphere does. Here we have used 0.5 dB for VHF band signal and smaller losses for higher frequency bands. The exact losses are as yet unknown because we do not know the collision frequency and irregularities in the Martian ionosphere. At Earth, these losses are about 3.0 to 10 dB for at 127 MHz. At Mars, this type of loss will be much smaller, because the Martian ionosphere is one order of magnitude thinner than Earth's. VHF band (400–500 MHz) waves have been used for communication between a rover and a lander (Mars Pathfinder) and between a lander and an orbiter. The ionospheric effects on these waves should be further studied.

Another important attenuation factor for Martian surface communication is multipath due to reflections from rocks and canyon walls. Mars Pathfinder and Viking landing areas showed a lot of rocks and hilly structures. The communication between a rover and a base station will be affected by rock distributions and the surface refraction coefficient. Because there have been no experiments yet to measure these parameters on Mars, we must extrapolate from Earth-based experiments. We do not expect that there are any significant differences in attenuation between rocks at Mars and Earth. Goldhirsh and Vogel [1998] have studied multipath effects for canyon and hilly environments. For 870-MHz waves, attenuation has a range of 2–7 dB, while for L-band (1.7 GHz), the attenuation is 2–8 dB. At higher frequencies, higher losses should be expected. Thus, surface rock attenuation is a potentially a large attenuation source.

Table 7-2. Radio Wave Attenuation Around Mars for Various Frequency Bands

	VHF (100–500 MHz)	S-Band (2–4 GHz)	X-Band (10–12 GHz)	Ka-Band (30–38 GHz)
Ionosphere (absorption & scintillation)	0.5 dB	0.15 dB	0.1 dB	0.05 dB
Troposphere (scattering)	0	0	0	negligible
Gaseous	0	0 dB	0 dB	0 dB
Cloud	0	0	0.05 dB	0.1 dB
Rain	0	0	0	0
Fog	0	0	0	0.1 dB
Aerosol (haze)	0	0	0	0.1 dB
Dust*	0.1 dB	0.3 dB	1.0 dB	3.0 dB
Total Vertical Losses	0.5 dB	0.45 dB	1.15 dB	3.35 dB

* Worst case

Figure 7-1 schematically shows all possible Martian communication links from a point of view of wave propagation. Attenuation values for each link at four frequency bands are listed in Table 7-3. For surface-to-surface propagation, we do not know what the actual loss is because there is not yet any rock attenuation experimental data. The total propagation loss between Mars and Earth is free-space loss, plus about an 8-dB atmospheric loss from both planets.

When we calculated total losses, we ignored medium loss through interplanetary space. Actually, interplanetary space is not empty. Propagation of radio waves on deep space paths is affected by solar wind particles, or extended solar corona in interplanetary space. Dust particles in space are believed to be responsible for zodiacal light [Halliday and McIntosh, 1980]. Quoted values of the density of interplanetary dust that have been noted are about 10^{-17} or 10^{-18} g/m^3 (10^{-23} or 10^{-24} g/cm^3). The total attenuation (A) is proportional to mass loading:

$$A = k_a \int \rho dl = k_a \rho l \tag{7-2}$$

where k_a is the coefficient (= 3 × 10^{-4} dB/m^2) [Flock, 1981], ρ is constant mass density (= 10^{-17} g/m^3), and l is the path length (= 4 × 10^{11} m). Because the dust abundance is so low and the particle sizes are so small, the attenuation effect on microwaves due to the dust of interplanetary space (1.2 × 10^{-9} dB) is negligible.

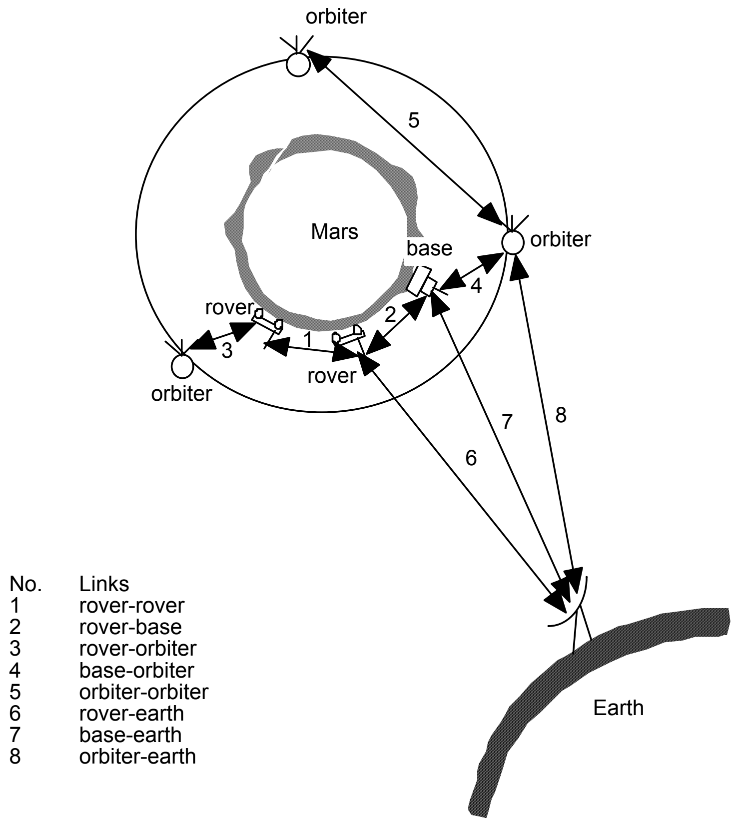

Figure 7-1. Telecommunication Links Around Mars from the Point of View of Radio Wave Propagation. There is a total of eight possible links between Mars and Earth.

Table 7-3. Attenuation for All Possible Links Between Mars and Earth

Link Type	VHF (100–500 MHz)	S-Band (2–4 GHz)	X-Band (10–12 GHz)	Ka-Band (30–38 GHz)
Rover-Rover*	—	—	—	—
Rover-Base*	—	—	—	—
Rover-Orbiter**	0.1 dB	0.3 dB	1.0 dB	3.4 dB
Base-Orbiter**	0.1 dB	0.3 dB	1.0 dB	3.4 dB
Orbiter-Orbiter**	0	0	0	0
Rover-Earth***	243 dB	263 dB	273 dB	283 dB
Base-Earth***	243 dB	263 dB	273 dB	283 dB
Orbiter-Earth***	240 dB	260 dB	270 dB	280 dB

* Depends on distance and terrain.

** Free space loss excluded.

*** Attenuation at the maximum distance between Mars and Earth, add 17 dB.

The solar corona and the solar wind consist of ionized gases: plasma. The electron density distribution of the solar corona has a strong dependence on the radial distance from the Sun

[Smith and Edelson, 1980]. At 1.1 R_s (solar radius) (1.1 × solar radius [6.96×10^5 km] = 7.66×10^5 km), the electron density is 1.25×10^{14} m^{-3}. At 4 R_s (2.78×10^6 km), the density is 1.2×10^{11} m^{-3}, which is less than the peak densities of the Martian ionosphere (2.5×10^{11} m^{-3}) and the Earth's ionosphere ($2.0 \times 10^{12} m^{-3}$). At 1 AU (215 R_s, 1.46×10^8 km), the solar corona density is 6.7×10^6 m^{-3}. The propagation path between Earth and Mars may closely approach the Sun when Mars is on the opposite side of the Sun relative to Earth. When the closest approach to the Sun is less than 4 R_s (that is, the propagation path passes through the deep solar corona close to superior conjunction), the solar wind plasma effect cannot be neglected. However, when the closest approach is greater than 4 R_s, because the solar wind plasma along the path is far less than the peak densities of both Martian and Earth ionospheres, the solar wind plasma effect is negligible.

References

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