Potential Interference from Wireless Water Tank Transmitters at Goldstone

C. Ho[1]

The Deep Space Network (DSN) facility in the Goldstone, California, area is considering installation of a new type of wireless transmitter (M2400S) within the facility. The transmitters will be used to monitor the water levels in several water tanks. Then these water-level signals will be transmitted to the nearby DSN facilities using transmitters operating in the UHF band (900-MHz) or S-band (2.4-GHz). This study is to evaluate the interference effects from the transmitters in adjacent DSN receiving stations. First we perform a terrain profile analysis to identify if there is a line of sight between each transmitter and the nearby DSN stations. After taking into account terrain shielding using high-resolution data, total propagation losses are calculated along each path. Then we perform the link analysis for each site to identify if the interference power exceeds the protection threshold of DSN receiving stations. As a result, we find that, because there is no bandpass filter installed in the transmitter system, interference power from the new transmitter at S-band will greatly exceed the protection criteria of broadband radio astronomy services (RAS) at S-band, such as Deep Space Station (DSS) 12 and DSS 28, by about 50 dB. The interference may also cause problems on all deep-space research stations at S-band, such as the Mars, Apollo, Venus, and Gemini sites. Without a sharp bandpass filter to suppress the out-of-band emissions in the frequency bands that the DSN station and RAS use, the author recommends not installing this type of transmitter within the Goldstone DSN facility area.

I. Background

Recently, the Goldstone NASA Deep Space Network (DSN) complex began planning to install a new type of transmitter within this area. This transmitter is a broadband wireless system, model M2400S, from the Trango Company [1]. The M2400S series comprises point-to-multipoint wireless broadband platforms transmitting at 2.4 GHz (S-band). The system supports up to 5 megabits per second (Mbps) at a range of 40 km. The transmitter will be used to transmit the monitoring signals of the water level from several water tanks within the Goldstone areas to the DSN facilities. This study examines the terrain profiles for three candidate sites where the transmitter will be installed and evaluates the terrain shielding effects. We will estimate the interference levels at S-band through the calculation of propagation losses

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[1] Communications Architectures and Research Section.

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between the transmitters and DSN antennas and compare these levels with protection criteria for DSN receiving stations. Finally, we will evaluate the feasibility of installing the transmitters in the Goldstone DSN complex.

II. Propagation Loss Calculation

There are several previous studies of interference after taking the terrain shielding on DSN facilities into account [2–5]. However, none of them was performed at such close distances, where the terrain diffraction is a dominant propagation mechanism for trans-horizon propagation among all anomalous modes. As we did before, to calculate the interference propagation loss, we need to perform the terrain-profile analysis first to identify whether or not there is a line of sight between the transmitter and receiver antennas. After we define the profiles, we can use the following procedures to calculate the propagation losses:

(1) If there is a line of sight (no hill blocking in between), the propagation loss for the path will be purely free-space loss.

(2) If there are hills in between (which block the line of sight), we will use the following terrain diffraction equations to calculate the additional losses due to the hills [6,7]. For a knife-edge hill, the additional diffraction loss $J(\nu)$ will be

$$J(\nu) = 6.9 + 20 \log \left(\sqrt{(\nu - 0.1)^2 + 1} + \nu - 0.1 \right) \text{ dB} \tag{1}$$

Here, the diffraction parameter ν is

$$\nu = h \sqrt{\frac{2}{\lambda} \left(\frac{d_1 + d_2}{d_1 d_2} \right)} = h \sqrt{\frac{2}{\lambda} \left(\frac{d}{d_1 d_2} \right)} \tag{2}$$

where λ is the wavelength, d_1 is the distance from transmitter to hill top, d_2 is the distance from hill top to receiver, d is the total distance between transmitter and receiver, and h is the obstacle (hill) height relative to the baseline linking the transmitter and receiver. Actually, here $\sqrt{\lambda d_1 d_2 / (d_1 + d_2)}$ is the first Fresnel length.

From Eqs. (1) and (2), we can see that higher-frequency (shorter-wavelength) radio signals suffer larger losses for terrain diffraction. Using these equations and the terrain parameters listed in the tables below for three sites, we can obtain the total diffraction losses for each path in S-band. These are the sums of the free-space loss L_{fs} and the additional diffraction loss $J(\nu)$.

A. Site One: Fort Irwin to Goldstone Guard House Areas

According to the proposal, a new transmitter with a 4.5-meter-high sector patch antenna will be mounted at the Fort Irwin pump house to transmit telemetry to the Goldstone guard house. Thus, the transmitter will be close to several large DSN antennas: Deep Space Station (DSS) 12 (Echo site), DSS 13 (Venus), and DSS 27 and DSS 28 (Gemini).

As the satellite map in Fig. 1 shows, the Fort Irwin pump house is 7.29 km from the east side of the Goldstone guard house. The plan is to install the transmitter at this pump house to transmit water-level signals using S-band. The azimuth angle of the guard house (gh) relative to the pump house (ph) is 287 deg (with respect to true north). The coordinates of the transmitter and DSS antennas with approximate latitude and longitude are listed in Table 1.

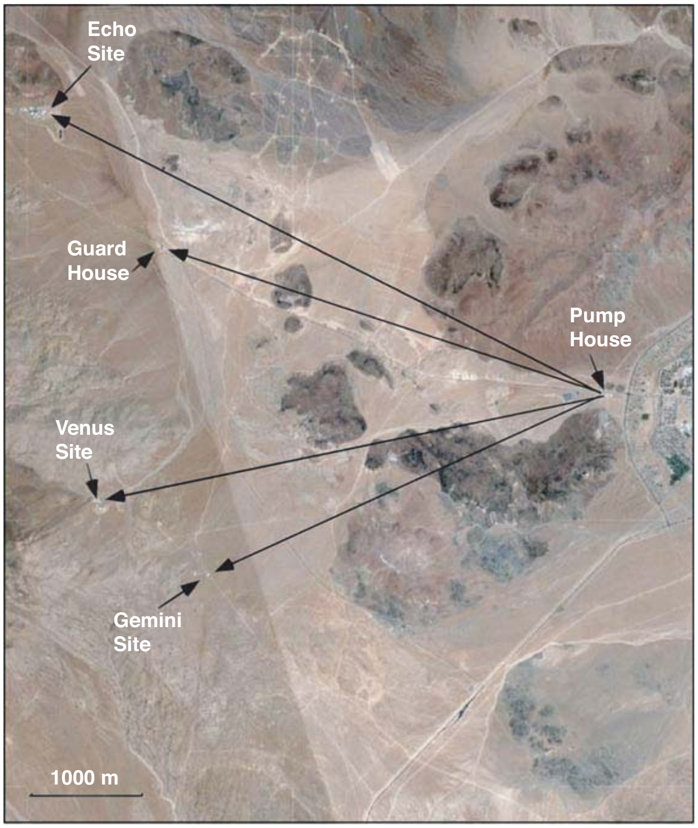

Fig. 1. Satellite map showing the approximate location of the transmitter installed at the Fort Irwin pump house and the DSN sites: guard house, Echo station, and Venus and Gemini Stations.

Table 1. Approximate coordinates of the transmitter and DSS antennas around the Fort Irwin site.

Antenna	Latitude, deg N	Longitude, deg W	Distance to ph, km	Antenna height, m
Fort Irwin pump house	35.26	116.71	—	5
Guard house	35.28	116.79	7.3	5
Echo: DSS 12 (34 m)	35.30	116.81	9.7	19
Venus: DSS 13 (34 m)	35.25	116.79	8.0	19
Gemini: DSS 27 (34 m)	35.24	116.78	6.8	19
DSS 28 (34 m)	35.24	116.78	6.9	19

Through the terrain profile analysis along the great circle, Figs. 2(a) through (d), we can see that there is a near line of sight from this transmitter to the Venus site (DSS 13) where we can calculate loss using the free-space loss. However, some hills do block the line of sight between the transmitter and receiving station, especially for the terrain profile between the pump house and the guard house, where two hills appear in between. This is a multi-knife-edge diffraction problem. The total diffraction loss is equal to the sum of two individual knife-edge losses. Terrain parameters measured and propagation losses calculated at 2.4 GHz for the paths are given in Table 2.

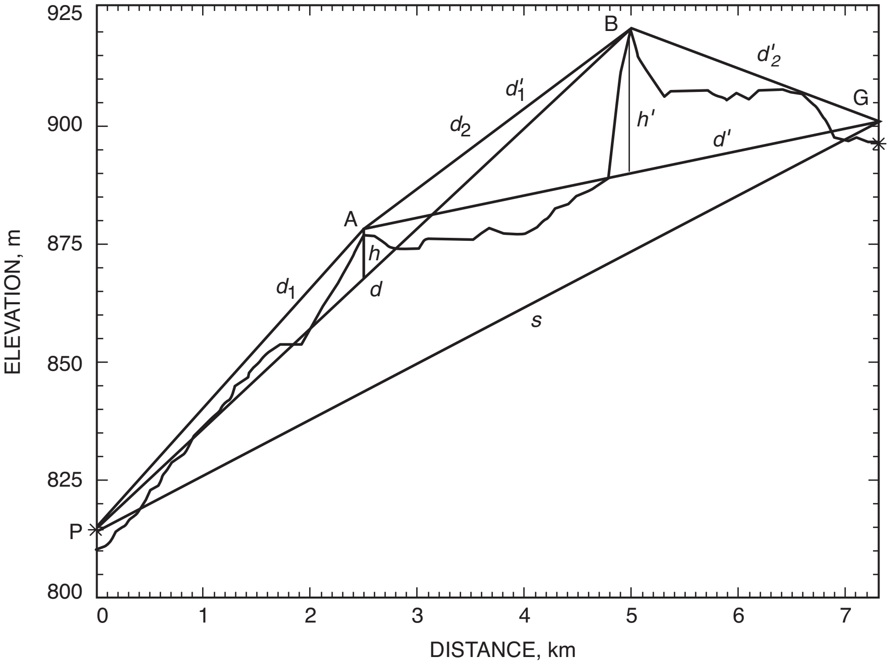

Fig. 2(a). Terrain profile between the pump house (P) of the water tank near Fort Irwin and the guard house (G).

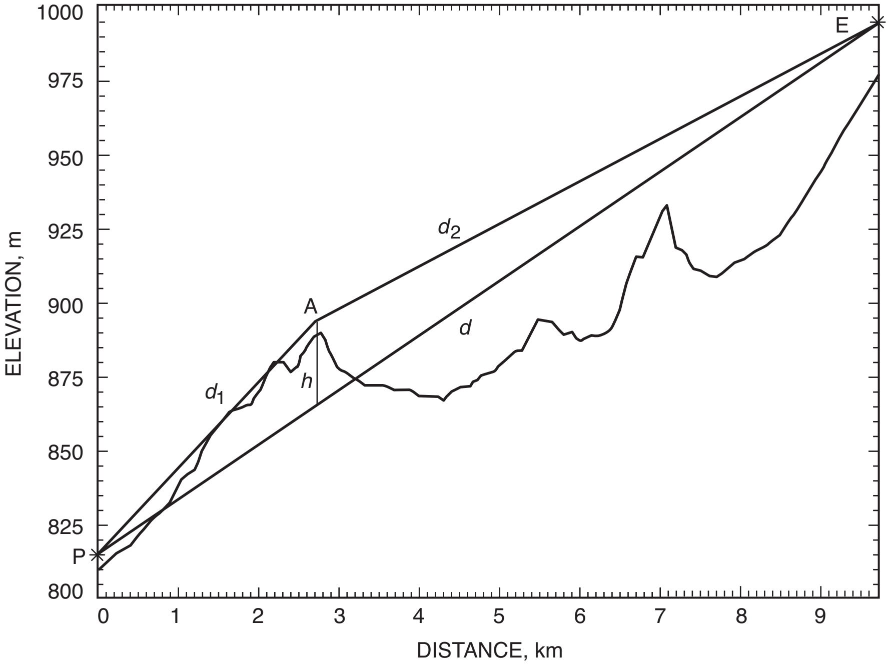

Fig. 2(b). Terrain profile between the pump house (P) of the water tank and the Echo site (E).

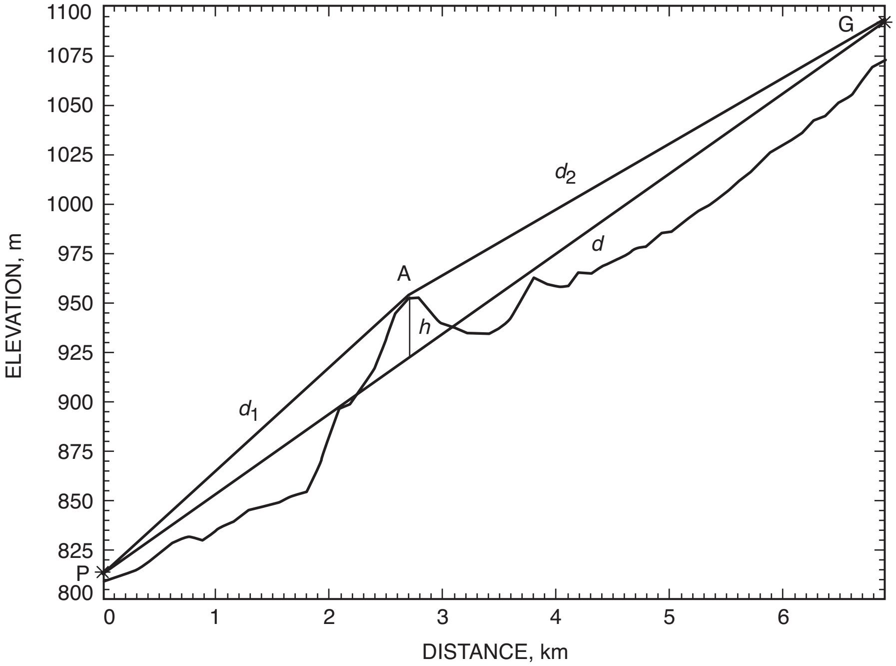

Fig. 2(c). Terrain profile between the pump house (P) of the water tank and the Gemini site (G).

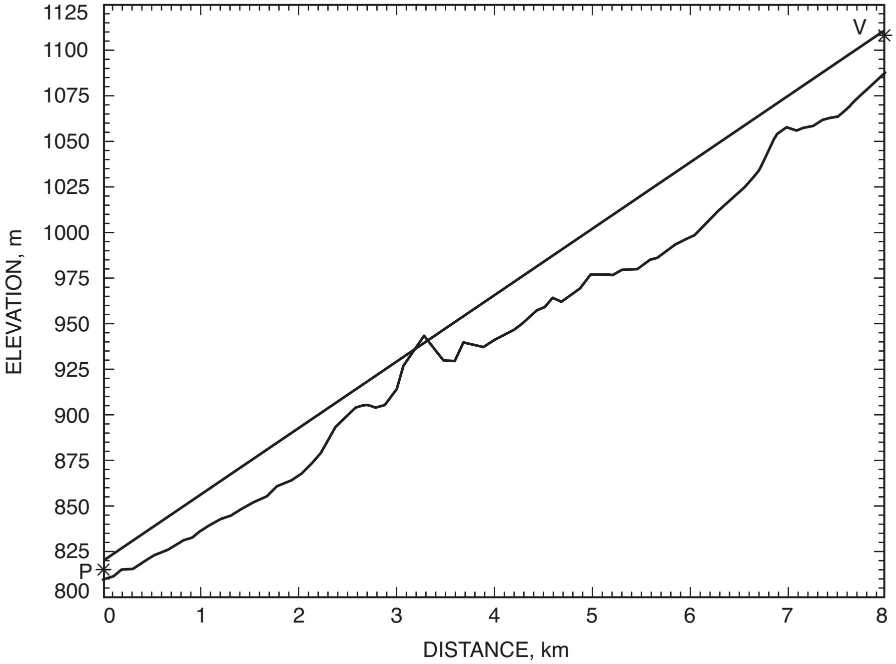

Fig. 2(d). Terrain profile between the pump house (P) of the water tank and the Venus site (V).

Table 2. Terrain diffraction parameters and total propagation losses for each path.

Path	d_1, m	d_2, m	d, m	h, m	ν, m	$J(\nu)$, dB	L_{fs}, dB	L_{tot}, dB	Required loss, dB	Margin, dB
Pump house to guard house	2500 2500	2500 2300	5000 4800	12 35	0.43 1.28	9.71 15.62	117.37	142.72	—	—
Ph to Echo (RAS)	2800	6900	9700	25	0.70	11.85	119.85	131.70	180.5	−48.8
Ph to Gemini (DSN)	2800	4100	6900	26	0.81	12.63	116.90	129.53	141.3	−11.8
Ph to Venus (DSN)	—	—	8000	—	—	—	118.18	118.18	141.0	−22.8

B. Site Two: Mars Site Area

According to the plan, the second transmitter, with a 4.5-meter-high antenna, will be mounted on a hillside that is near the 70-m antenna (Mars site) at Goldstone, but separated by a small hill, as shown in Fig. 3. As the satellite map shows, Point A (there is a water tank at this location right now) is the potential location for installation of this new transmitter, while Point B is the 70-m antenna (DSS 14). The distance between them is 2.4 km. The azimuth angle of Point A relative to Point B (70-m antenna) is 153 deg (with respect to true north). Coordinates of both antennas are listed in Table 3.

Figure 4 shows the terrain profile between the water tank and the Mars station along the great circle. We can see that there is a small hill that blocks the line of sight between the two antennas. The hill has a height of 1116 m (above mean sea level) and a height of 105 m relative to the baseline linking the two antennas.

Using the knife-edge diffraction model, we find that the propagation loss between the two antennas at S-band is as follows:

(1) Free-space loss over this 2.4-km path: $L_{fs}(2.4\text{ GHz}) = 107.67$ dB

(2) Diffraction Loss due to this small hill: $L_{df}(2.4\text{ GHz}) = 38.22$ dB

(3) Total propagation loss between the water house and DSS 14: $L_{tot}(2.4\text{ GHz}) = 145.89$ dB

C. Site Three: Apollo Site Area

According to the plan, the third transmitter, with a 4.5-meter-high antenna, will be mounted at the Apollo site. It will be used to transmit the monitoring signals of the water level from the Apollo water tank. Thus, this new transmitter is very close to the five large DSN antennas (DSS 16, DSS 23, DSS 24, DSS 25, and DSS 26) in the Apollo area (from 1.2 to 1.5 km).

Figure 5 shows the Apollo site in a satellite map. The water tank is at the east side of the Apollo antenna site. A transmitter will be installed around this water tank to transmit water-level signals using UHF (900-MHz) or S-band. The azimuth angle of the water tank relative to DSS 16 (26-m antenna) is 87 deg (with respect to true north), and the distance in between is 1.2 km. Table 4 lists the coordinates of the transmitter and DSS antennas.

Figures 6(a) through (d) show the terrain profiles for four paths along the great circle. We can see that they all have a line-of sight view from the wireless transmitter to the five DSN antennas. There is no hill or terrain blocking the line of sight because the water tank is at a relatively high location. The free-space propagation losses between these paths at the two frequency bands are listed in Table 5.

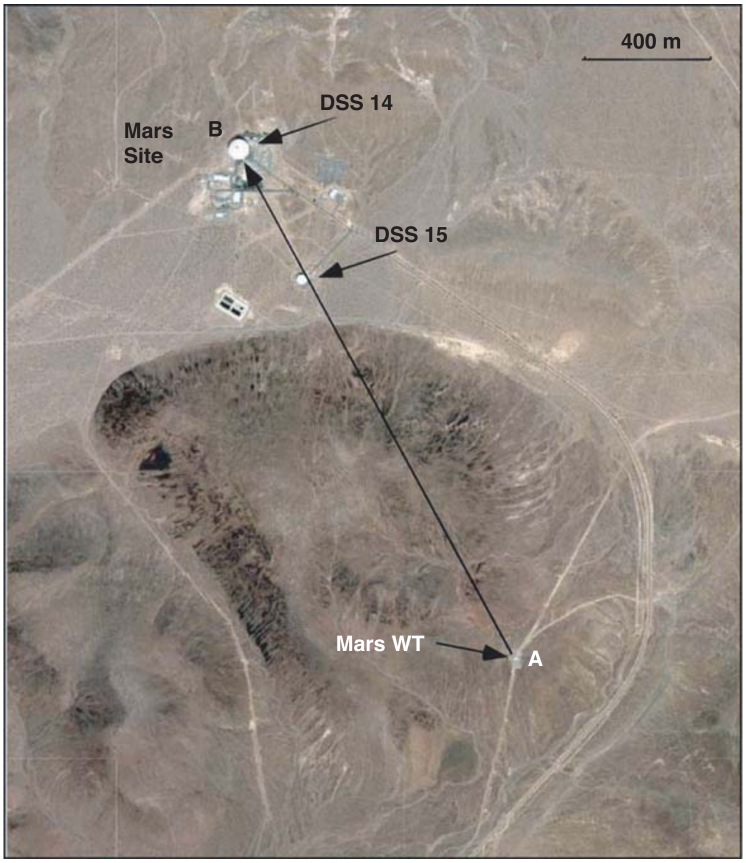

Fig. 3. Satellite map showing the location of the transmitter at the water tank (A) and the Goldstone 70-m antenna (the Mars site, B).

Table 3. Approximate coordinates of the transmitter and DSS antennas around the Mars site.

Antenna	Latitude, deg N	Longitude, deg W	Elevation, m	Antenna height, m
Point A (Water tank)	35.41	116.88	981	5
Point B (DSS 14)	35.43	116.89	1006	37

III. Interference Link Analysis

After propagation losses over the terrain for each path are calculated, we can perform the link analysis to calculate the interference levels at each DSN receiving station site. To give an example, we have performed a link analysis for Site 1 in this article. Two types of deep-space victim receiving stations will be considered in this study: radio astronomy and deep-space research stations. We will examine whether the potential interference from the transmitters exceeds the protection threshold for these victim stations.

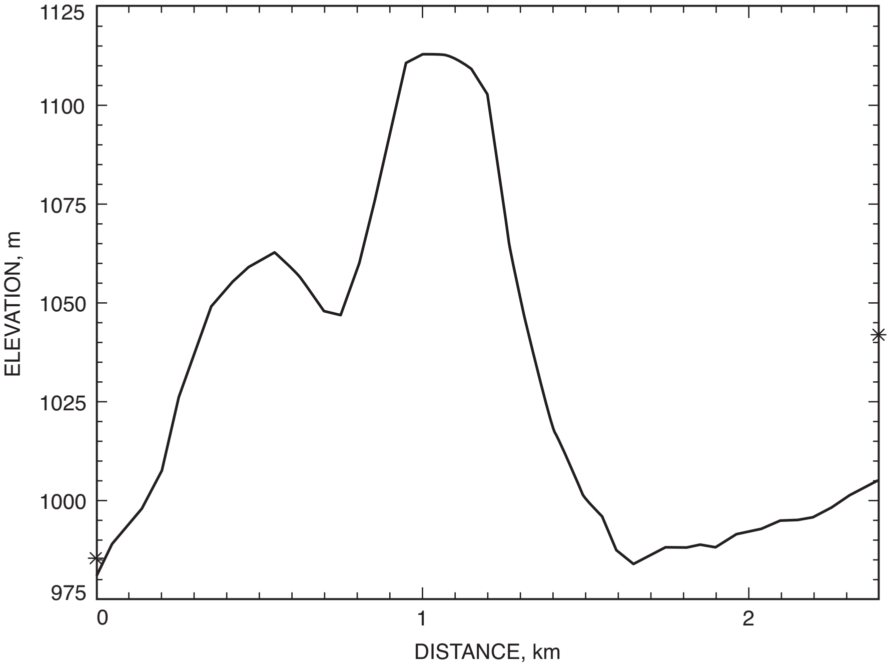

Fig. 4. Terrain profile between the two antennas (wireless transmitter near the water tank and the Mars site 70-m DSN antenna) along the great circle.

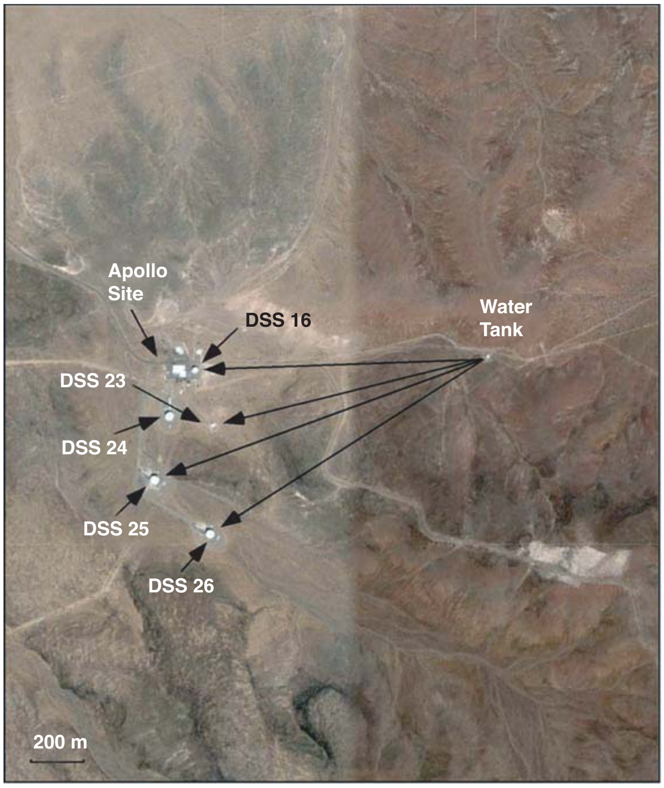

Fig. 5. Satellite map showing the Apollo site area and location of the water tank relative to the five DSN antennas (DSS 16 and DSS 23 through DSS 26).

Table 4. Approximate coordinates of the transmitter and DSS antennas around the Apollo site.

Antenna	Latitude, deg N	Longitude, deg W	Distance to water tower, km	Antenna height, m
Apollo water tank	35.34	116.86	—	5
DSS 16 (26 m)	35.34	116.87	1.2	15
DSS 23 (11 m)	35.34	116.87	1.2	7
DSS 24 (34 m)	35.34	116.87	1.3	19
DSS 25 (34 m)	35.34	116.88	1.5	19
DSS 26 (34 m)	35.34	116.87	1.4	19

A. Transmitter Specifications

Based on the available information, the new wireless transmitter (M2400S) operates in a frequency band of 2400 to 2483 MHz; the maximum output power is 23 dBm (−7 dBW) with a 5-MHz channel bandwidth (up to 5-Mbps data rate); and the transmitter antenna gain is 17 dBi. For a worst-case scenario, we assume that the transmitter exactly points to the victim DSN receiving station. Thus, its effective isotropic radiated power (EIRP) in power spectral density (PSD) is

$$\mathrm{EIRP_{PSD}} = P_t + G_t = -7[\mathrm{dBW}] - 67[\mathrm{dBHz}] + 17[\mathrm{dBi}] = -57[\mathrm{dBW/Hz}] \tag{3}$$

Because the transmitter does not have a bandpass filter to suppress the out-of-band emissions, it is assumed that the transmitted power spectral density will roll off according to $(\sin x/x)^2$. Based on a theoretical model, the nth side-lobe power will be reduced by $2/(\pi n)^2$ relative to its main lobe [8]. Figure 7 shows the power spectral density of the transmitted signal and its separation from the downlink frequency band of nearby deep-space research stations [Fig. 7(a)] and the radio astronomy services (RAS) band [Fig. 7(b)]. All parameters for the transmitter are given in Table 6.

B. Deep Space Research Stations

Deep-space receiving Earth stations use 2290 to 2300 MHz as their downlink frequency band. This is separated by 100 MHz from the lower end (2400 MHz) of the transmitter frequency band. The 21st side lobe of the transmitted spectrum will fall into the DSN band. Without any filtering, the 21st side lobe will be down from its peak power by 33.3 dB. Thus, the interference power transmitted at the 2300-MHz band will be −90.3 dBW/Hz.

The protection criterion for deep-space research stations is established by the International Telecommunication Union (ITU) as −222 dB (W/Hz) in power spectral density in the band near 2 GHz (Recommendation SA.578) [9]. It is applicable for DSS 13 (Venus) and the Gemini stations (DSS 27 and DSS 28). The minimum propagation loss required for the transmitter to meet the DSN protection criterion can be calculated. To calculate the loss, we have used the DSN receiving antenna gain (G_r) based on the off-boresight angle of interference sources relative to the main beam of the receiving antenna as described below.

The DSN receiving antenna mechanically can point its main beam as low as 6 deg in elevation angle relative to the horizon. For two DSN station sites (Venus and Gemini), based on high-resolution terrain data, we find that the elevation angles of DSS 13 and DSS 28 relative to the transmitter located at the Fort Irwin pump house are −2.06 and −1.88 deg, respectively. Thus, the minimum off-boresight

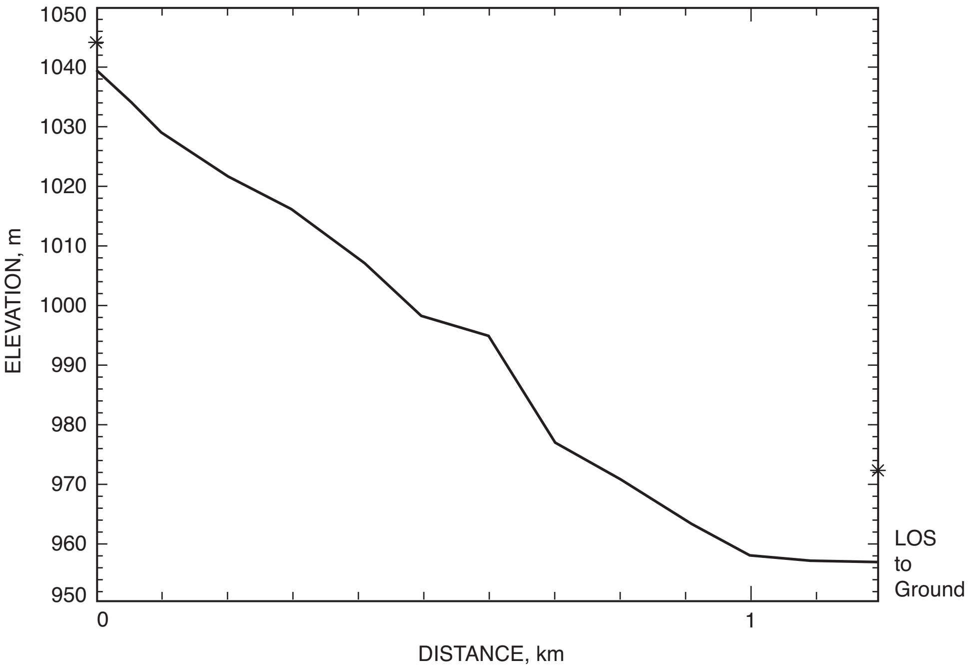

Fig. 6(a). Terrain profile between the Apollo water tank and DSS 16.

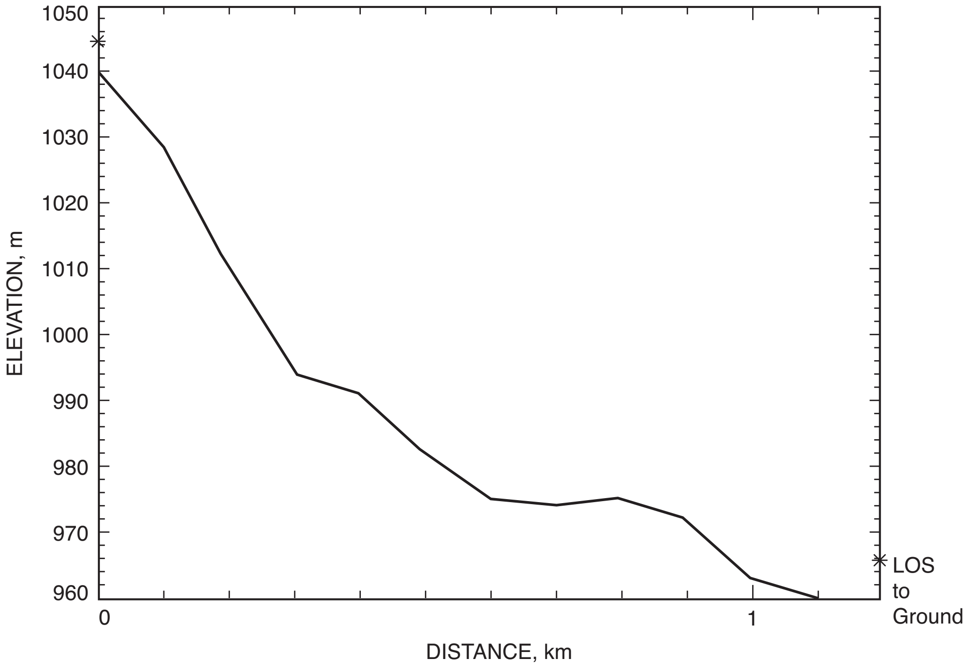

Fig. 6(b). Terrain profile between the Apollo water tank and DSS 23.

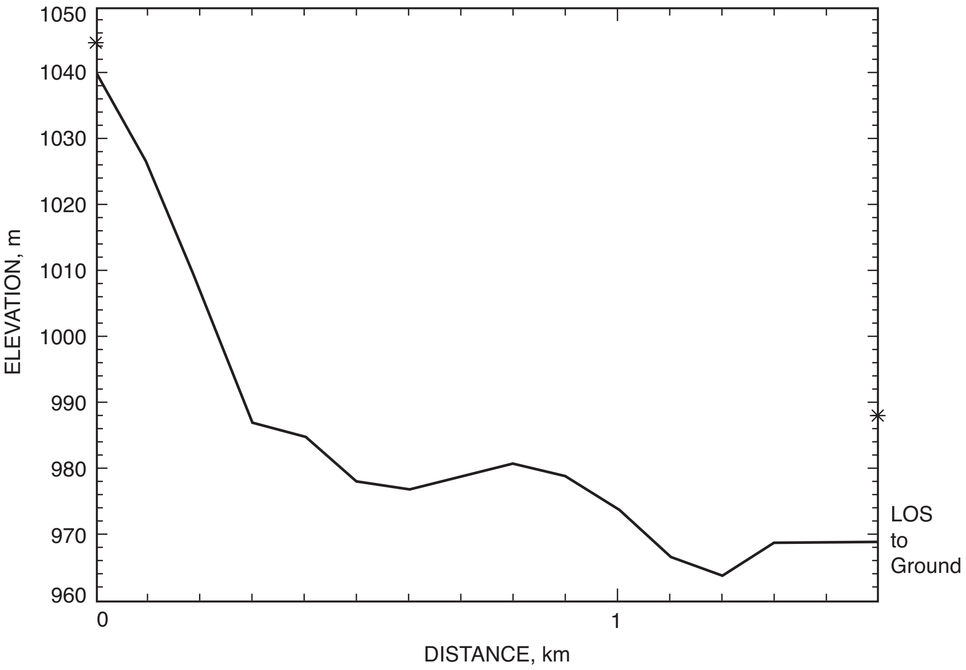

Fig. 6(c). Terrain profile between the Apollo water tank and DSS 25.

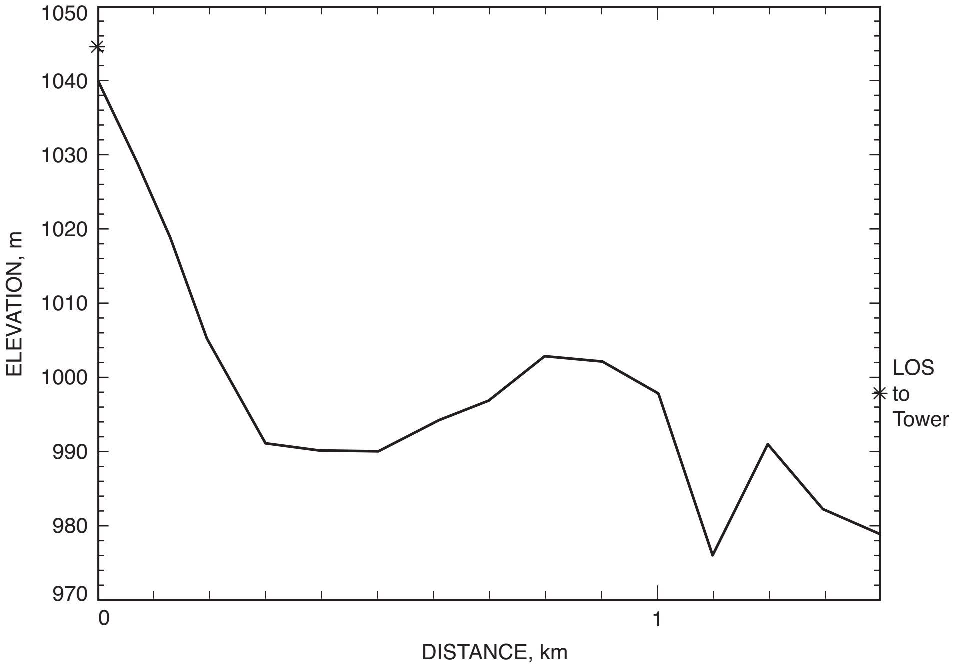

Fig. 6(d). Terrain profile between the Apollo water tank and DSS 26.

Table 5. Propagation losses around the Apollo site for each path.

Path	Loss at 0.9 GHz, dB	Loss at 2.4 GHz, dB
DSS 16 to water tank	93.16	101.7
DSS 23 to water tank	93.16	101.7
DSS 24 to water tank	93.86	102.4
DSS 25 to water tank	95.10	103.6
DSS 26 to water tank	94.50	103.0

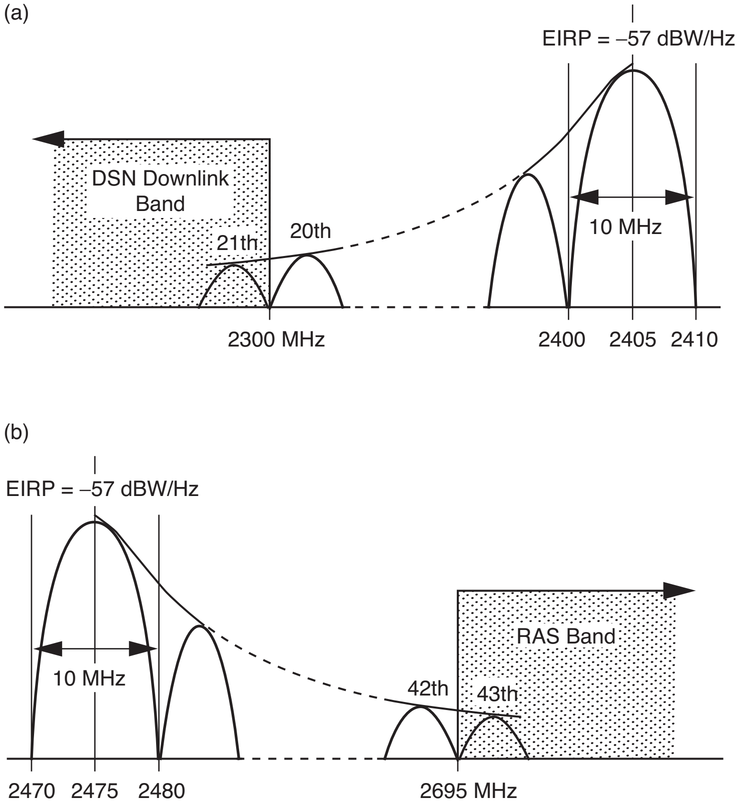

Fig. 7. Power spectral density from the wireless transmitter at S-band and its frequency separation from (a) the DSN receiving stations and (b) the RAS.

angles of the pump house transmitter relative to the main beams of DSS 13 and DSS 28 are 8.06 and 7.88 deg, respectively. Using these angles and the antenna model described in ITU F.699 [10], the maximum antenna gains in the directions of the interference source (pump house) are calculated as 9.3 dB (for the Venus site) and 9.6 dB (for the Gemini site).

Using the receiving antenna gain, we find that the minimum loss required to meet the protection criteria is 141.0 dB. We can see that none of the propagation losses calculated from the above terrain profile analysis satisfy this requirement. The propagation loss between the pump house and the Venus site is only 118.2 dB, about 22.8 dB lower than required, as given in Table 7. For the Gemini site, it is about 11.8 dB lower than the required level. Unless the transmitter also has a 23-dB bandpass filter to

Table 6. M2400S model transmitter parameters.

Parameter	Symbol	Value	Value in dB	Comment
Transmitting frequency	f	2.4 GHz	—	2400–2483 MHz
Transmitter power	P_t	—	−7 dB(W)	23-dBm output
Transmitter antenna gain	G_t	—	17 dBi	Maximum gain
EIRP	EIRP	—	10 dB(W)	—
Transmitting data rate	—	5 Mbps	—	—
Transmitting bandwidth	B	5 MHz	67 dB(Hz)	—
Transmitter power spectral density	P_{SD}	—	−57 dB(W/Hz)	—

Table 7. Interference analysis for the DSN receiving station.

Parameter	Symbol	Value	Comment
Frequency separation from transmitter	Δf	100 MHz	—
Out-of-band roll-off	—	33.3 dB	Based on theoretical model
Propagation loss to Venus (DSS 13)	L	118.2 dB	—
Off-boresight angle	—	8.06 deg	Separation from terrain elevation angle
DSN receiver antenna gain in direction of interference	G_r	9.3 dBi	—
Received interference in PSD	P_r	119.2 dB(W/Hz)	—
Interference protection criteria for DSN	P_{th}	−222 dB(W/Hz)	From ITU SA.578
Margin	—	−22.8 dB	—

suppress the out-of-band interference, the transmitter will cause a serious interference problem for the DSN receiving stations by greatly exceeding the protection criteria.

C. Radio Astronomy Services

Radio astronomy stations operate at 2695 MHz for radio astronomy continuum observations. This is 215 MHz away from the upper end of the transmitter bandwidth. The 43rd side lobe falls into the RAS band, and its power is 39.6 dB below the peak power. Thus, the interference power spectral density at the RAS band is −96.6 dBW/Hz.

DSS 12 (Echo site) is used for RAS to receive the broadband continuum radiation from the sky for the Goldstone Apple Valley Radio Telescope (GAVRT) project [11]. DSS 28 may also be used for this purpose in the future. For RAS, its maximum acceptable interference level is −247 dBW/m^{2}Hz (ITU RA.769) [12] in power spectral flux density at S-band.

Assuming the 0-dBi receiving antenna gain for the RAS station as suggested by the ITU, the minimum required propagation loss is 180.5 dB in order to meet the RAS protection criterion. It is obvious that

Table 8. Interference analysis for the RAS receiving station.

Parameter	Symbol	Value	Comment
Frequency separation from transmitter	Δf	215 MHz	—
Out-of-band roll-off	—	39.6 dB	Based on theoretical model
Propagation loss to Echo Station (DSS 12)	L	131.7 dB	—
Isotropic antenna gain	A	30.09 dB(/m^2)	$4\pi/\lambda^2$
RAS receiving antenna gain	G_r	0 dBi	Assumed gain for RAS
Received interference in power spectral flux density	P_{sfd}	198.2 dB(W/m^{2}Hz)	—
Interference protection criteria for RAS	P_{th}	−247 dB(W/m^{2}Hz)	From ITU RA.769
Margin	—	−48.8 dB	—

the propagation loss from the above terrain profile analysis between the pump house and the Echo site (131.70 dB) does not satisfy this requirement, as shown in Table 8. It is 48.8 dB less than the propagation loss needed according to the interference protection criterion set up by ITU Recommendation RA.769. If DSS 28 (the Gemini site) will also be used for radio astronomy services in the future, the propagation loss is 51 dB less than what is required.

IV. Conclusions

Because the new transmitter does not have a bandpass filter to suppress the out-of-band emission, it will cause potential interference to the nearby radio astronomy services stations—Echo site (DSS 12) and possibly DSS 28. The power of interference from the wireless transmitter will be 48.8 dB above the protection criteria for RAS. The new transmitter also can potentially interfere with other DSN receiving Earth stations, such as DSS 13 (Venus), DSS 14 (Mars), and the Apollo site (DSS 16 and DSS 23 through DSS 26). The minimum propagation loss required to satisfy the protection criteria for the receiving station is 141 dB. At the Apollo site, there is line of sight between the transmitter and the DSN receiving stations, and the free-space loss between them is only 101.7 dB, exceeding the protection criteria by ~40 dB. If a bandpass filter with a 50-dB alternation can be added to suppress the out-of-band emissions in the bands the DSN station and the RAS use, the protection criteria will be met. Otherwise, it is recommended that the DSN not install this type of transmitter in these areas as is currently planned.

Acknowledgments

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