A Monte Carlo Simulation Study of Interference Effect from Multiple HDFS Transmitters above 30 GHz

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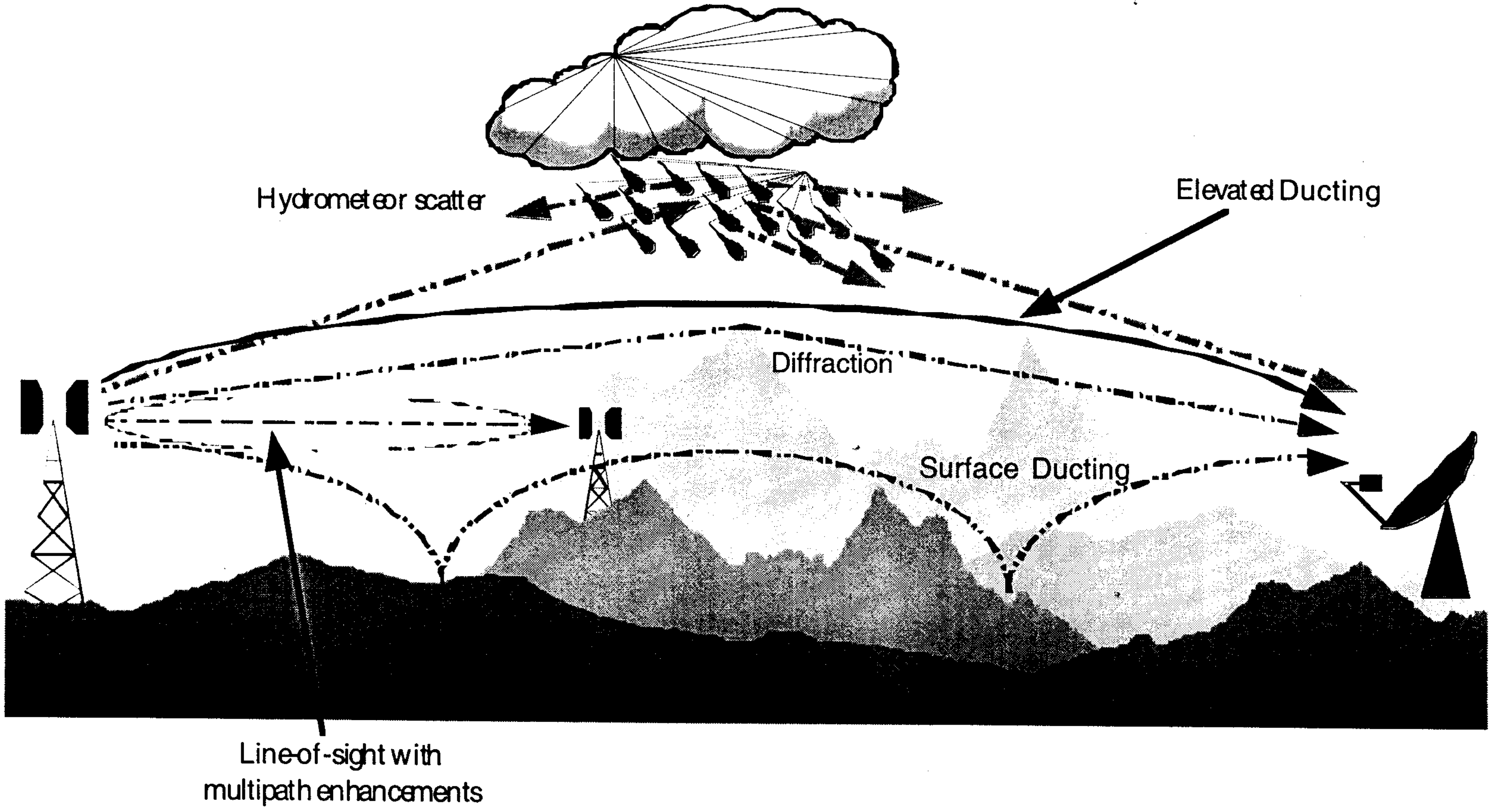
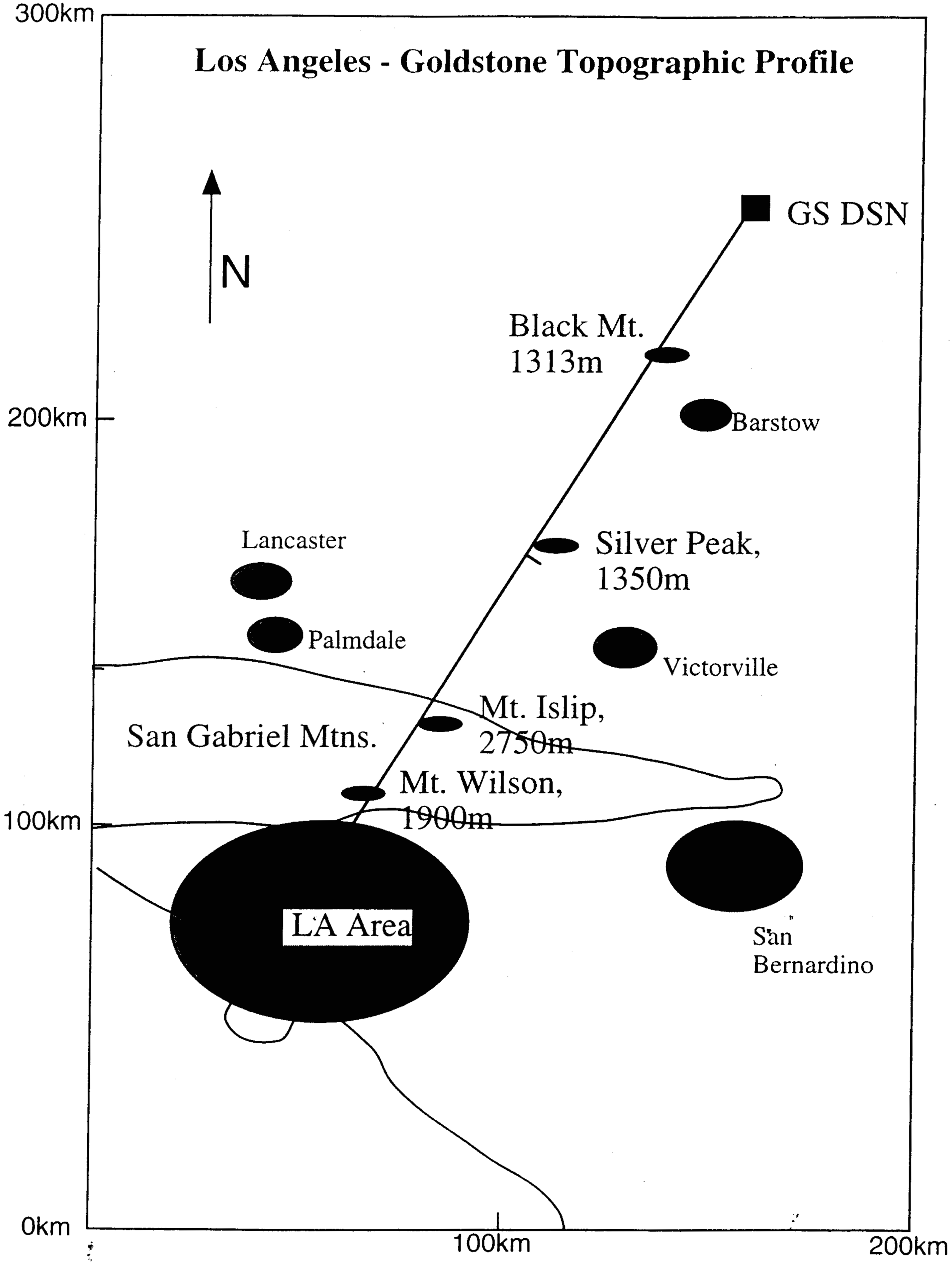
Background

- Commercial operators are now proposing to install hundreds and thousands of High Density Fixed Services (HDFS) microwave transmitters in large urban center, such as Los Angeles.
- These transmitters will share the same frequencies in the Ka band (32 GHz and 37-38 GHz) as some Space Research Service (SRS) receiving earth stations.
- To face this challenge, Resolution 126 (WRC-97) has requested the ITU-R to conduct, as a matter of urgency and in time for WRC-99, appropriate studies to determine sharing criteria between stations in the Fixed service and stations in other services which are allocated, respectively.
- The three DSN tracking stations worldwide utilize this frequency band and may become vulnerable to interference from the planned deployments of HDFS transmitters.
- These HDFS transmitters operate at relatively strong signal power (up to -60 dBW/Hz), they will seriously interfere with the sensitive DSN receivers.
- It has become imperative to accurately predict the impact of HDFS transmitters on NASA's DSN receivers in the Ka band.

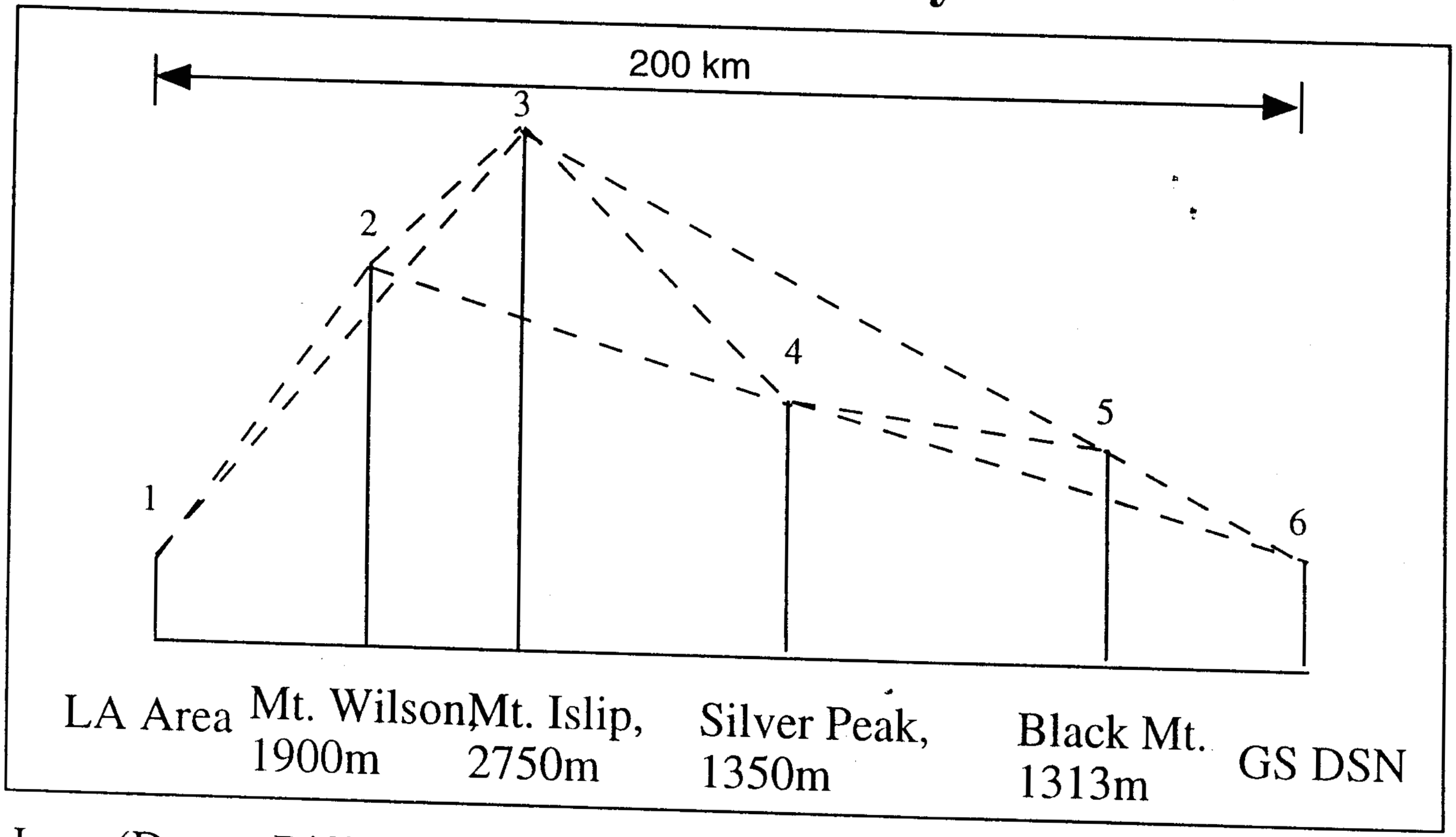
Interference Propagation Mechanisms





Los Angeles - Goldstone Topographic Profile

Path Profile Analysis



Loss (Due to Diffraction) = Loss (Free Space Spread) + Loss (Diffraction at 4 Mts.)
= 188 dB + 33 dB = 221 dB

Three types of Transmission Losses include:

Diffraction Effect (< 200 km),
Rain Scattering Effect (<300 km)
Ducting Effect (Trans-horizan)

HDFS Transmitter Antenna Model

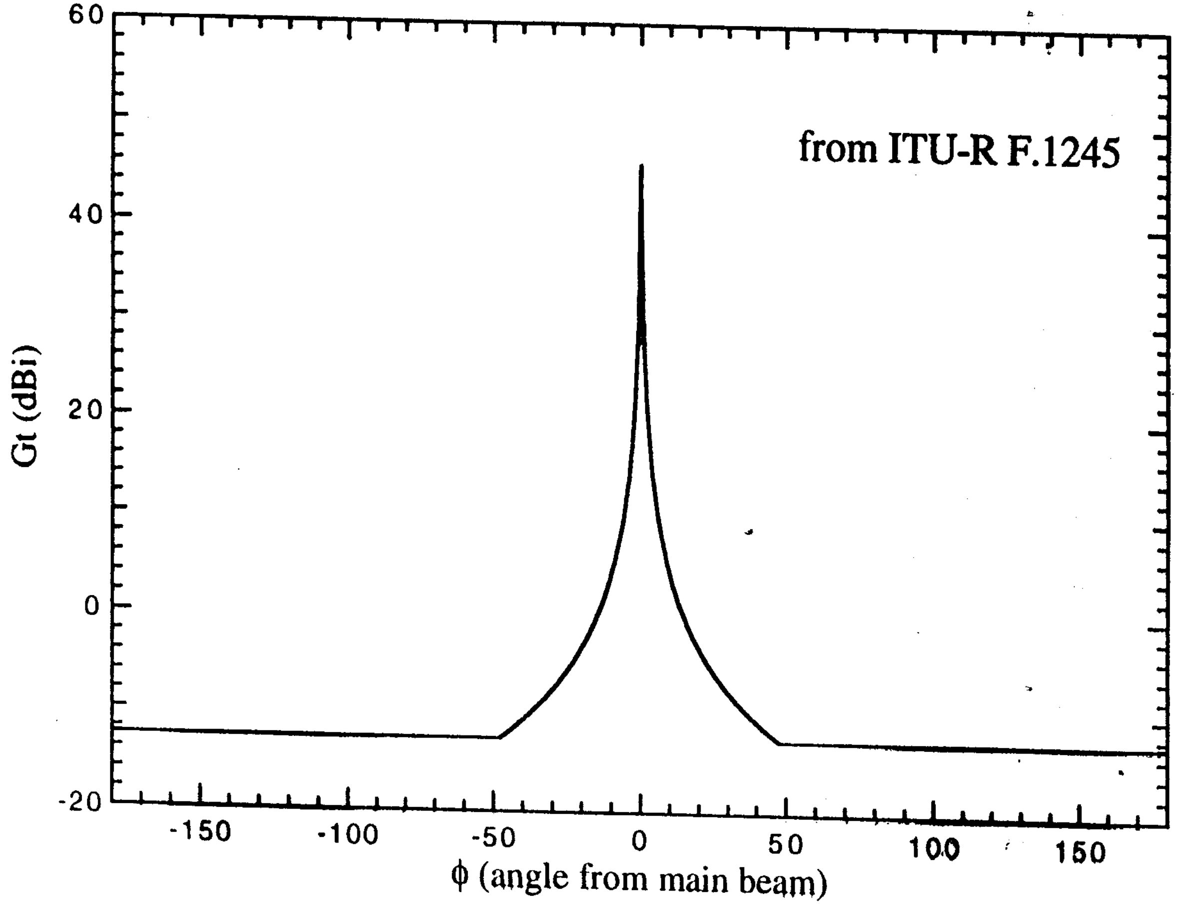
Based on Document ITU-R F.1245, transmitter gain G_t as a function of azimuthal angle (φ):

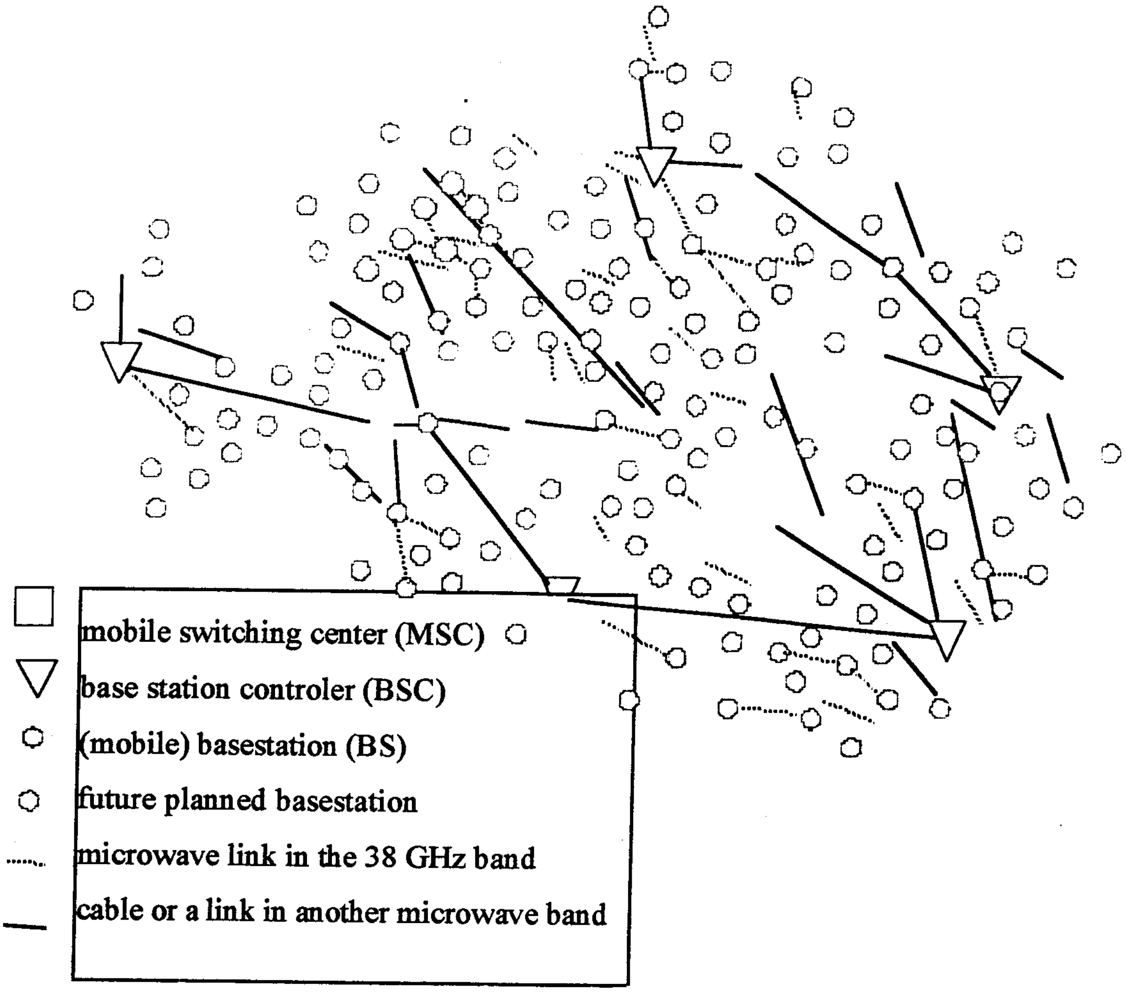
$$
\begin{aligned}
G_t(\varphi) &= 46 - 2.5\times10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 && \text{for } 0^\circ \le \varphi < \varphi_m \\
G_t(\varphi) &= 29 - 25\log\varphi && \text{for } \varphi_m \le \varphi < 48^\circ \qquad (1) \\
G_t(\varphi) &= -13 && \text{for } 48^\circ \le \varphi \le 180^\circ
\end{aligned}
$$

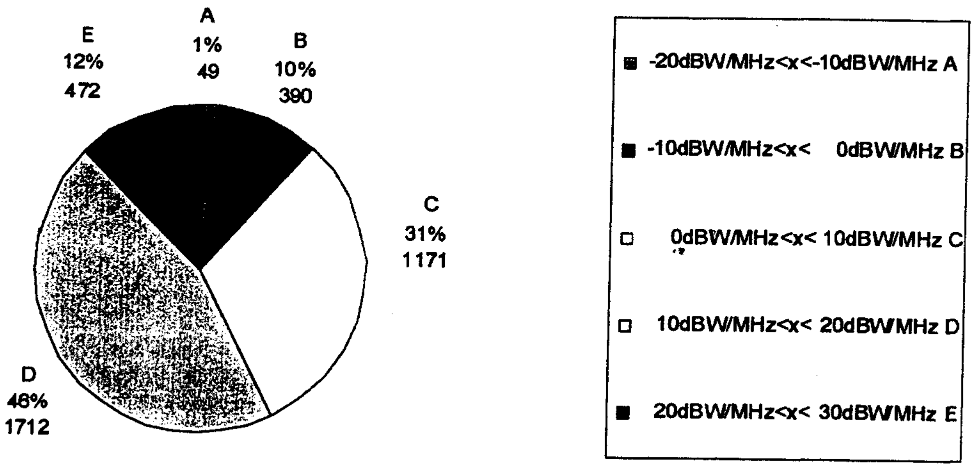
where D is antenna diameter (0.8 m), λ is wavelength for 32 GHz wave (0.0094 m) and φ_m (first sidelobe angle) is 1.4°.

Thus for a transmitter with main lobe gain of 46 dB, the maximum $EIRP = P_t + G_t$ = -60 dBW/Hz + 46 dB = -14 dBW/Hz

HDFS Microwave Transmitter (Point to Point) Model







EIRP - Classes (dBW/MHz) for 38 GHz microwave
on the base of 3794 terminals
EIRPmax. = 26,9 dBW/MHz; EIRPmin. = -21,2 dBW/MHz

TABLE 2

TABLE 16 of Recommendation F.758-1

Representative characteristics of point-to-multipoint systems operating in the range 30-40 GHz

System No.	Hub No. 1	Remote No. 1	Hub No. 2	Remote No. 2	Hub No. 3	Remote No. 3
Capacity/data rate	DS-3 45 Mbit/s	DS-3 45 Mbit/s	OC-3 155 Mbit/s	OC-3 155 Mbit/s	OC-6 310 Mbit/s	OC-6 310 Mbit/s
Modulation type	OQPSK	OQPSK	16-QAM	16-QAM	256-QAM	256-QAM
Necessary bandwidth (MHz)	50	50	50	50	50	50
Tx power (dBW)	0	–13	5	–10	7	–4
Antenna gain (dBi)	16	29	18	33	28	39
Transmit e.i.r.p. (dBW)	16	16	23	23	35	35
Antenna beamwidth (degrees)	45 or 90	1.9	45 or 90	1.7	45 or 90	1.7
Antenna polarization	H/V	H/V	H/V	H/V	H/V	H/V
Rx noise figure (dB)	7	7	5	6	5	5
Rx noise temperature (K)	1 740	1 740	1 160	1 450	1 160	1 160
Rx sensitivity, (1×10^{-6} BER) (dBW)	–110	–110	–102	–101	–90	–90
Maximum interference (dB(W/MHz))	–146.2	–146.2	–148.0	–147.0	–148.0	–148.0

TABLE 1

Characteristics of Point-to-Point Fixed Systems in the 37-39.5 GHz Band Extracted from Table 15 of Recommendation ITU-R F.758 & more

Characteristic	For Systems in the 37-39.5 GHz Band				
Modulation	4-FSK	4-FSK	4-FSK	4-FSK	16-QAM
Capacity	2x2 Mbit/s	8 Mbit/s	2x8 Mbit/s	34 Mbit/s	155Mbit/s
Channel Spacing, MHz	3,5	7	14	28	56
Max. Antenna Gain, dBi	47 *	47 *	47 *	47 *	47 *
Min. Multiplexer Loss, dB	0	0	0	0	0
Antenna Type	Dish	Dish	Dish	Dish	Dish
Max. Tx Power, dBW	0	0	0	0	0
EIRP (max) dBW	47	47	47	47	47
Rx IF Bandwidth, MHz	2	4	8	17	40
Rx Noise Figure, dB	11	11	11	11	8
Rx Thermal Noise, dBW	-130	-127	-124	-121	-120
Nominal Rx Input Power, dBW	-112 + M	- 109+M	- 106+M	- 103+M	- 99+M
Rx Input Power, dBW for $1*10^{-3}$ BER	-115	-112	-109	-106	102
Nominal short-term Int. , dBW	-	-	-	-	-
Nominal long-term Int. , dBW	-140	-137	-134	-131	-130
Equivalent power, dB(W/MHz)	-	-	-	-	-
Spectral Density, dB(W/MHz)	-143	-143	-143	-143	-146
Applicable Notes	**2 and 4**	**2 and 4**	**2 and 4**	**2 and 4**	**2 and 4**

* 0.9 m dish assumed

Note 2: Specified interference will reduce system C/N by 0.5 dB. (Interference level is 6 dB below receiver noise floor.)

Note 4: The specified interference level is total power within the receiver bandwidth.

Transmission Loss Models

1. Line of Sight (Free Space Loss)

For a line of sight propagation, the received power P_r is defined as

$$P_r = \frac{P_t G_t G_r}{L_b} = \frac{P_t G_t G_r}{L_{fs} L} \qquad (2)$$

where $L_b = L_{fs} L = \frac{P_t G_t G_r}{P_r}$ is basic transmission loss and $L_{fs} = (\frac{4\pi df}{c})^2$ is free space loss, d is distance between the receiver and transmitter and c is speed of light, P_t is transmitter power and G_r is receiver antenna gain. Thus, there is a general relation in logarithm

$$P_r = EIRP + G_r - L_b \qquad \text{in dB} \qquad (3)$$

Furthermore,

$$L_{fs} = 20[\log(4\pi / c) + \log f + \log d] \quad \text{in dB} \qquad (4)$$

Changing units of frequency *f* from Hz to GHz, and *d* from meter to km, we have

$$L_{fs} = 92.45 + 20\log f + 20\log d \qquad \text{in dB} \qquad (5)$$

In equation (2), *L* is the correction term for loss:

$$L = A_g + A_d \qquad \text{in dB} \qquad (6)$$

where, A_g is gaseous attenuation [23], A_d is defocus factor due to the Earth curvature, and,

$$A_g = (\gamma_0 + \gamma_w)d = 0.2d \qquad (8)$$

where γ_o is loss from oxygen and γ_w is from water vapor (in dB/km). Thus

$$L_b = L_{fs} + L = L_{fs} + A_g + A_d \qquad \text{in dB} \qquad (7)$$

When $f = 32$ GHz, and $d = 200$ km, we have $L_b = 188$ dB

2. Diffraction Over Mountains

Diffraction loss L_d is defined as

$$L_d = L_b + L_{ds} = L_b + \sum_i J_i(v) \qquad \text{in dB} \qquad (9)$$

where $L_{ds} = \sum_i J_i(v)$ is all sub-path diffraction over edges and troughs in the path profiles, $J(v)$ is a function defined in document [17]. For a 200 km path profile between Los Angeles and Goldstone, there are 4 major mountain peaks. Total sub-path diffraction loss is

$$\sum_i J_i(v) = 33 dB$$

Thus, total loss due to diffraction is 221 dB over a 200 km path from Los Angeles to Goldstone.

3. Trans-horizon Ducting (mode 1)

For a transhorizon ducting propagation along the great circle of the Earth, the transmission loss L_1 is a function of p , percentage of time of weather condition

$$L_1(p) = 92.5 + 20\log f + 10\log d_1 + A_h + [\gamma_d(p) + \gamma_o + \gamma_w]d_1 \quad \text{dB} \quad (10)$$

Ducting propagation has an one dimensional loss (10 log d_1) due to tropospheric layer trapment. Taking $\gamma(p) = 0.01 + \gamma_d(p) + \gamma_o + \gamma_w$,

$$L_1(p) = 120 + 20\log f + \gamma(p)d_1 + A_h \qquad \text{dB} \quad (11)$$

Transmission loss for the ducting as a function of percentage of time exceeded is plotted in Figure 3 for different distances. When $p = 0.001$, $d_1 = 200$ km, $\gamma_d\, d_1 = 38$ dB. Thus

$$L_1(0.001) = 208 \text{ dB}$$

Corresponding to a larger p, there is a larger loss L_1, or smaller interference. Similar to Equation (3), the received interference power is given by

$$P_r(p) = EIRP + G_r - L_1(p) \qquad \text{dB} \quad (12)$$

4. Rain Scattering (mode 2)

For the rain scattering transmission loss L_2, the received interference power is independent on receiver antenna gain.

$$L_2(p) = \frac{P_t}{P_r} \tag{13}$$

From the radar equation, we have

$$P_r = \frac{P_t G_r \eta V A_r}{(4\pi)^2 (R_1)^2 (R_2)^2} \tag{14}$$

$$L_2(p) = 168 + 20\log d_2 - 20\log f - 13.2\log R - G_t + 10\log A_b - 10\log C + \Gamma + \gamma_g d_2 \quad \text{dB} \tag{15}$$

where R is the rain rate, a function of percentage of time of weather condition, A_b, C and Γ are other correction factors. The loss as a function of p, percentage of time exceeded is plotted in Figure 4 for different distances. For $p = 0.001$ in Rain zone E, 200 km distance, and a transmitter gain $G_t = 46$ dB, we have $L_2 = 160$ dB. $L_2^*(p) = L_2(p) + G_t = 206$ dB.

Summary of Transmission Losses

For a single transmitter with

Distance (d) = 200 km; frequency (f) = 32 GHz; time percent (p) = 0.001%,

we have:

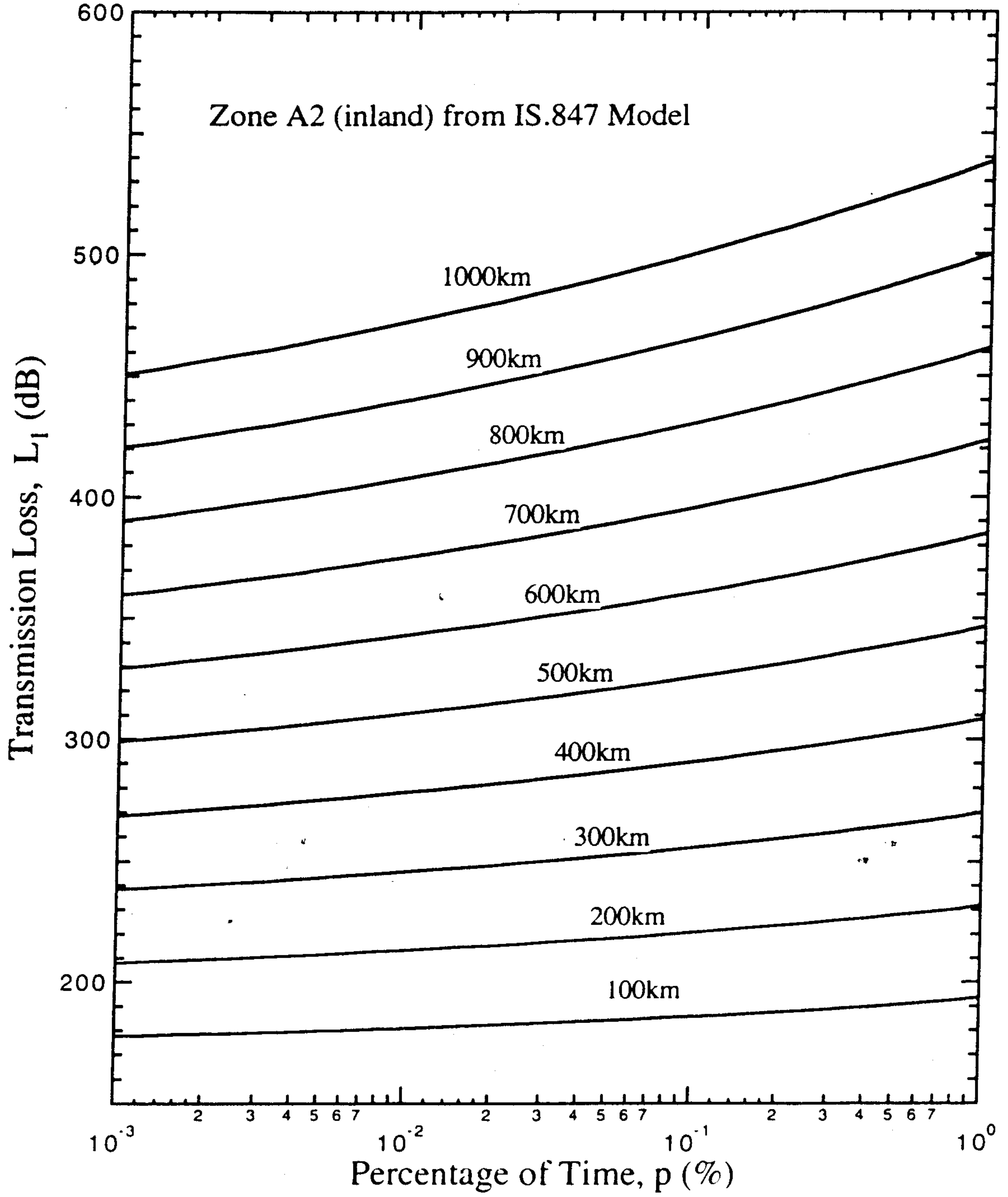
Line of sight Loss (including gaseous attenuation): $L_b = 188$ dB

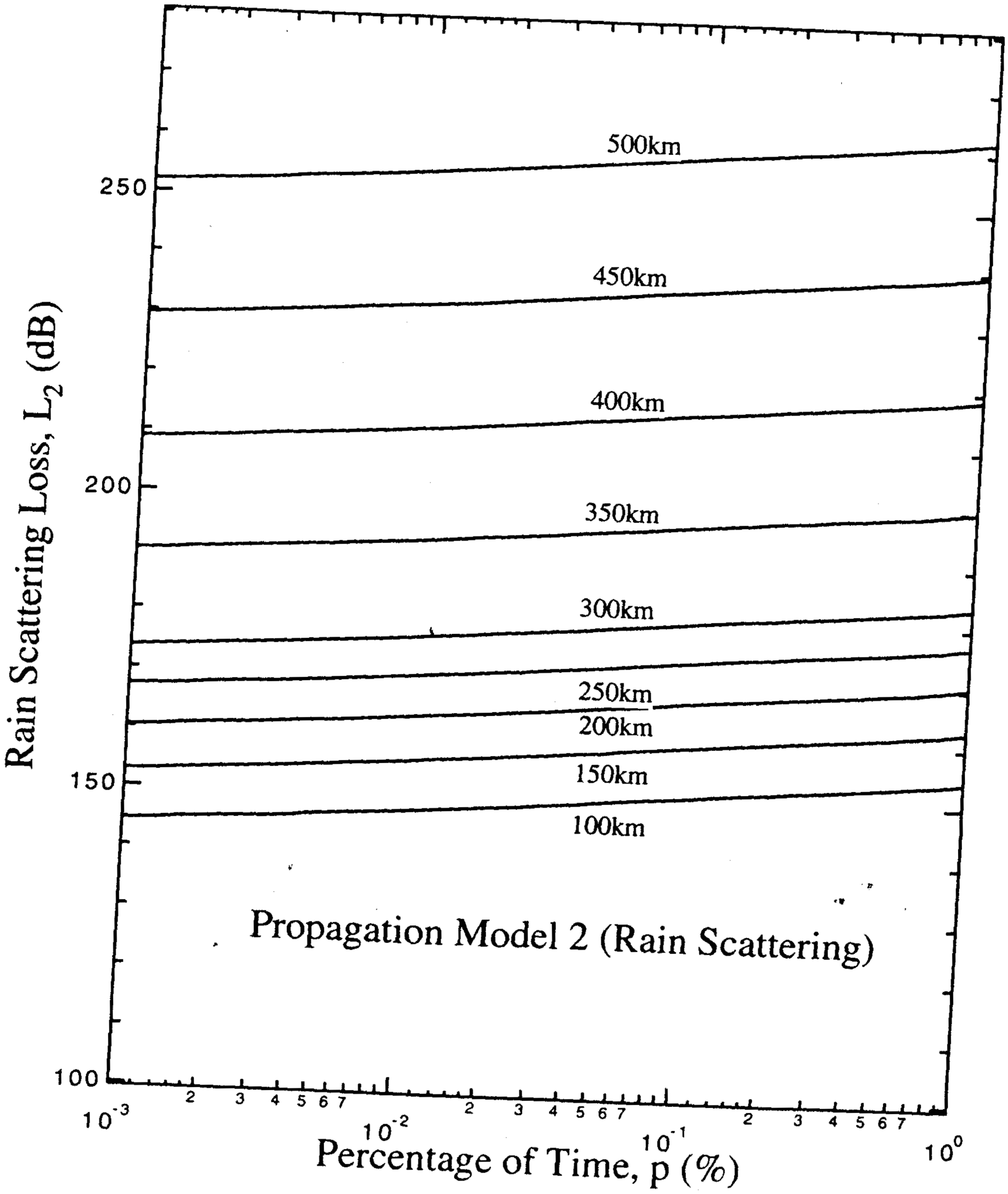
Diffraction loss over mountains: $L_d = 221$ dB

Ducting transmission loss (0.001 percentage time): $L_1 = 208$ dB

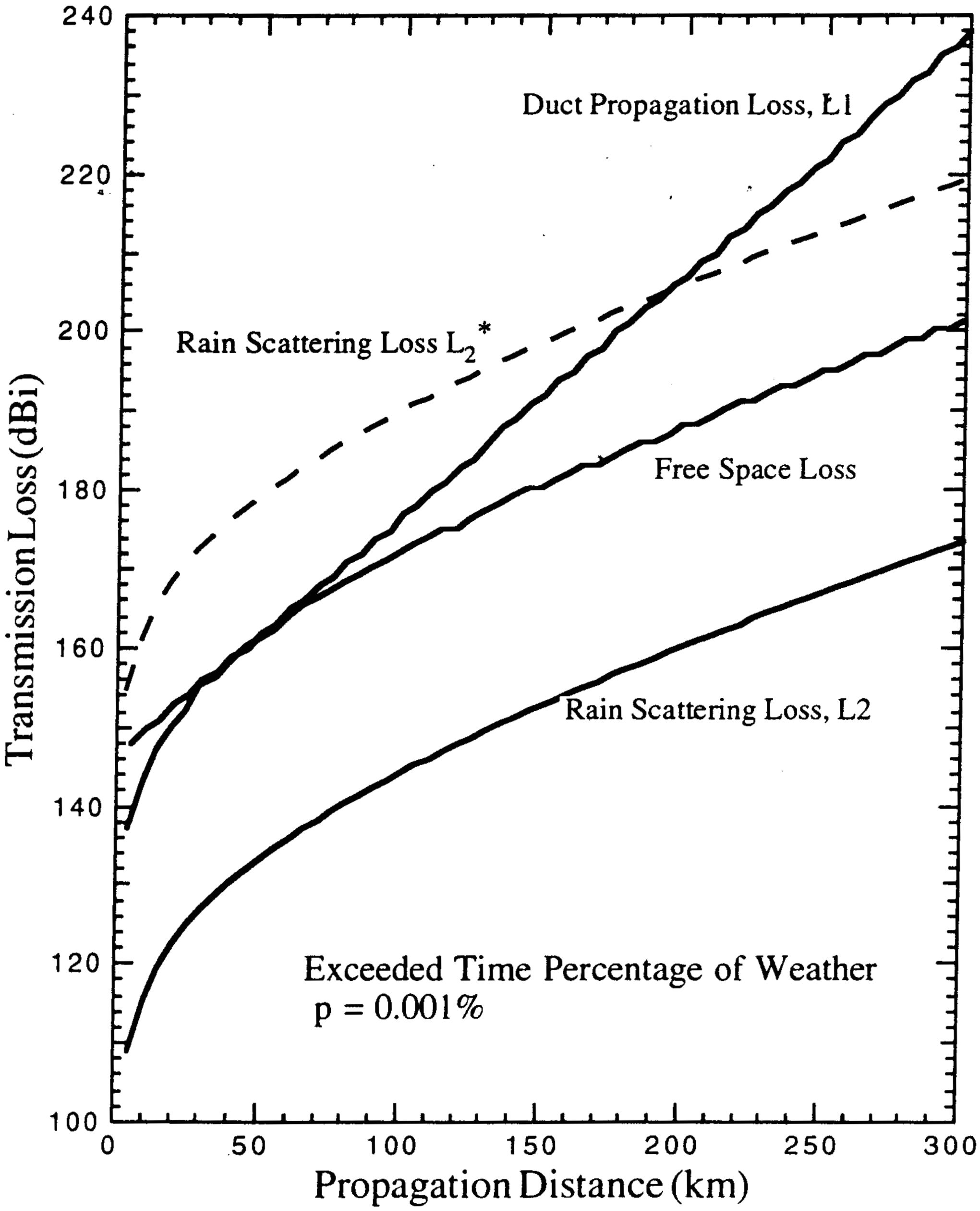
Rain scattering loss (0.001 percent time): $L_2^* = 206$ dB

Transmission Loss for Propagation Mode (1)-Great Circle Mechanism




500km
450km
400km
350km
300km
250km
200km
150km
100km
250
200
150
100
Rain Scattering Loss, L_2 (dB)
10^{-3}
2
3
4
5
6
7
10^{-2}
2
3
4
5
6
7
10^{-1}
2
3
4
5
6
7
10^{0}
Percentage of Time, p (%)
Propagation Model 2 (Rain Scattering)

Transmission Losses as a Function of Distance



DSN Receiver Model

Documented in ITU Radio Regulations for the DSN antenna pattern with the following parameters:

DSN antenna with a diameter $D = 70$ m;

threshold power spectral flux density $p_d = -251$ dBW/m^{2}Hz at Ka band;

corresponding threshold power spectral density $P_{th} = \zeta\pi(D/2)^2 p_d = -217$ dBW/Hz,

where antenna efficiency $\zeta = 52\%$,

main lobe gain at boresite is 85 dB and

back lobe gain is -10 dB.

Worst-Case Estimate of HDFS Interference Effects on DSN Receiver at 32 GHz for Single Transmitter

- HDFS Transmitter Model:
  - Transmitter power: $P_t = 0$ dBW/MHz = -60 dBW/Hz (Strongest case)
  - Frequency: 32 GHz
  - Elevation angle: 0° horizontal
  - Main lobe (Maximum Gain): 46 dBi
  - Back lobe gain: -12.5 dB
  - EIRP: $P_t + G_t = -60$ dBW/Hz + 46 dBi = -14 dBW/Hz

- Transmission Loss Model:
  - Distance, d = 200 km; Frequency, f = 32 GHz, Time percent, p = 0.001%
  - Line of sight Loss: $L_b = 188$ dBi
  - Diffraction Loss: $L_d = 221$ dBi
  - Ducting Loss: $L_1 = 208$ dBi
  - Rain Scattering Loss: $L_2^* = 206$ dBi

- DSN Receiver Antenna Model:
  - Size: D = 70 m
  - Threshold Power Density: $p_d = -251$ dBW/m²Hz
  - Threshold Receive Power $P_r = \eta\pi (D/2)^2 p_d = -217$ dBW/Hz,
  - where $\eta = 52\%$
  - Main lobe gain: 85 dBi
  - Back lobe gain: -10 dBi

Worst Case Estimate of Interference Effect for Single Transmitter from Los Angeles on Goldstone DSN Receiver

Transmitter $P_t = -60$ dBW/Hz, $G_t = 46$ dBi (main-lobe), -12.5 dB (side-lobe), EIRP = -14 dBW/Hz

Distance $d = 200$ km, probability $p = 0.001\%$

Receiver $G_r = 85$ dB (main-lobe), -10 dB (side-lobe), threshold $P_{th} = -217$ dBW/Hz

	EIRP	Loss	EIRP-Loss	P_r (dBW/Hz)		Margin $(P_{th} - P_r)$*	
				Side-lobe	Main-lobe	Side-lobe	Main-lobe
Line of Sight	-14	188	-202	-212	-117	-5	-100
Diffraction	-14	221	-235	-245	-160	**28**	-57
Ducting	-14	208	-222	-232	-147	**15**	-70
Rain Scattering	-14	206	-220	-220	-220	**3**	**3**

* Negative margin indicates the protection level criterion is exceeded

Worst Case Estimate of Interference Effect from Nearby City Single Transmitter on Goldstone DSN Receiver

Transmitter P_t = -60 dBW/Hz, G_t = 46 dBi (main-lobe), -12.5 dB (side-lobe), EIRP = -14 dBW/Hz

Probability $p = 0.001\%$ for ducting, rain scattering losses

Receiver G_r = 85 dB (main-lobe), -10 dB (side-lobe), threshold P_{th} = -217 dBW/Hz

							Pr (dB(W/Hz) Rain Scattering		Pr (dB W/Hz) Ducting		Margin (P_{th}-P_r)*	
	Distance from GS	EIRP dBW/Hz	LOS dBi	Diffraction dBi	Ducting dBi	Rain Scattering	sidelobe	mainlobe	sidelobe	mainlobe	sidelobe (Rain)	mainlobe (Ducting)
Barstow	50 km	-14	161	163	162	133	***-148***	-148	-186	***-91***	**-69**	**-126**
Victorville	65 km	-14	165	169	166	137	***-151***	-151	-190	***-95***	**-66**	**-122**
Lancaster	150 km	-14	180	193	192	153	***-167***	-167	-216	***-121***	**-50**	**-96**
Palmdale	160 km	-14	183	198	197	154	***-168***	-168	-221	***-126***	**-49**	**-91**

* Negative margin indicates the protection level criterion is exceeded

Monte Carlo Simulation Procedure

- **Three independent random variablrs representing HDFS 2D transmitter location and antenna orientation**

  for transmitter location with ranges:

  $0 \le \rho_i \le \rho_0$ (=1, 10, 30 and 50 km) radial distance

  $-180° \le \phi_i \le 180°$ azimuthal angle for mainbeam

  For transmitter antenna mainlobe azimuthal angle (φ):

  $$-180° \le \varphi_i \le 180°$$

  Assuming Los Angeles City Center has a geographic coordinate (x_c, y_c)

  The *ith* transmitter's location is

  $$X = x_i + x_c$$

  $$Y = y_i + y_c$$

  where

  $$x_i = \rho_i \cos \phi_i,$$

  $$y_i = \rho_i \sin \phi_i$$

- **Assuming ducting propagation**.

  At a Distance, d = 200 km; Time percent, $p = 0.001\%$, ducting Loss:

  $L_1 = 208$ dBi

- **Total Interference Power Spectral Flux Density P_{SFD} from all transmitters are linearly superposed**

  $$P_{SFD} = \sum_{i}^{n} (P_t + G_t(\varphi_i) - L_1(\rho_i, \phi_i))$$

- **We have made 1200 trials using 3000 transmitters. Each run has different transmitter pattern (in location and orientation)**

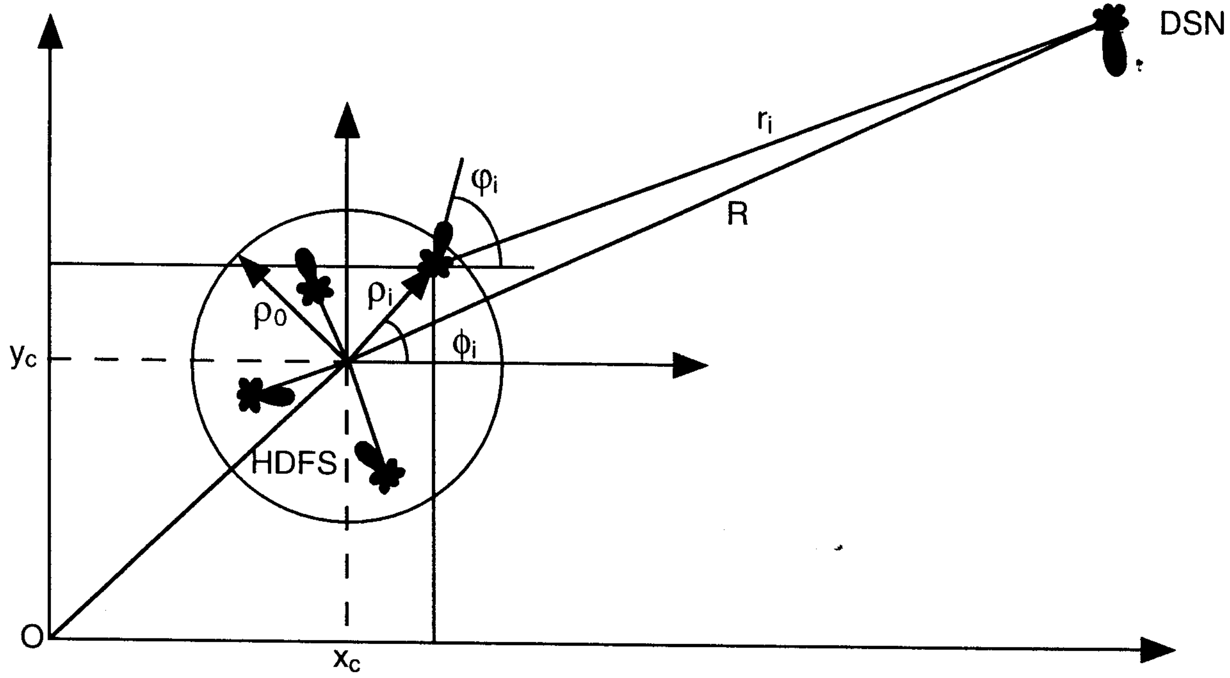


Figure 6. HDFS spatial distribution configuration and simulation variables. Transmitters are deployed in a circular area with a maximum radius ρ_0 around the center of Los Angles. Each transmitter has a random location (ρ_i,ϕ_i) and a mainbeam orientation φ_i. Goldstone DSN receiver has a distance r_i from the receiver and a 200 km distance from the city center.

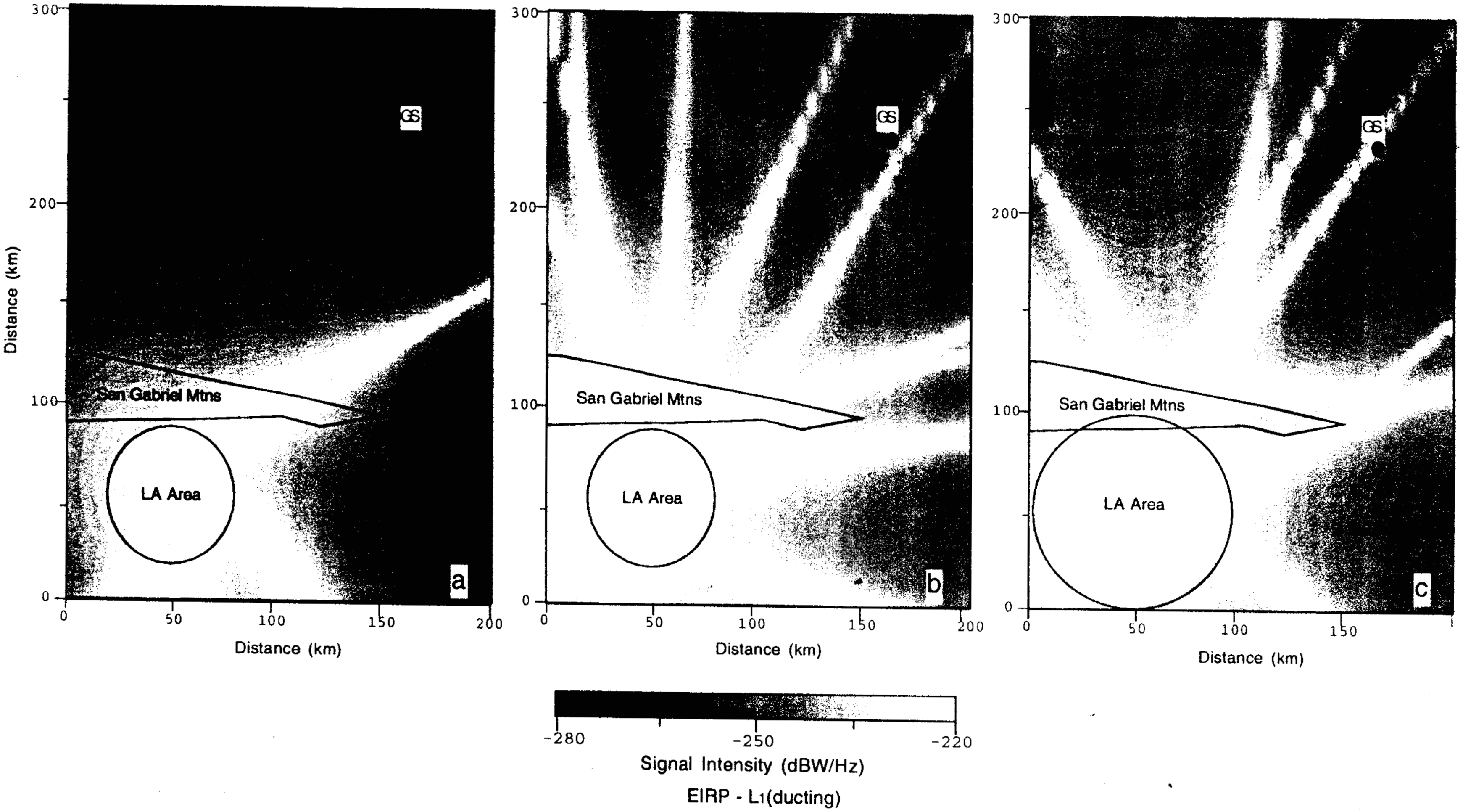


Figure 7. Interference signal intensities for various numbers of transmitters from Los Angeles area and extended radius. a) 5 transmitters with 30 km radius; b) 20 transmitters with 30 km radius; c) 20 transmitters with 50 km radius. Goldstone DSN receiver is at upper-right coner.

Monte Carlo Simulation of Interference Effect from Los Angeles Area HDFS on Goldstone DSN Receiver

Total 1200 runs, each run (or pattern) uses 3000 transmitters

Each Transmitter $P_t = -60$ dBW/Hz, $G_t = 46$ dBi (main-lobe), -12.5 dB (side-lobe), EIRP = -14 dBW/Hz

Probability $p = 0.001\%$ for ducting transmission only, $L_1 = 208$ dBi at distance d = 200 km

Receiver $G_r = 85$ dB (main-lobe), -10 dB (side-lobe), threshold $P_{th} = -217$ dBW/Hz

Maximum radial Distance (km)	Average Power Flux P_{SFD} at GS dBW/Hz	Aggregate EIRP (dBW/Hz) $P_{SFD} + L_1$	Equivalent Antenna Gain G_0 EIRP - P_t	Pr (dBW/Hz)		Margin $(P_{th}-P_r)$*	
				sidelobe	mainlobe	sidelobe	mainlobe
1 km	-212.5	-4.5	55.5	-222.5	-127.5	5.5	-89.5
10 km	-211.5	-3.5	56.5	-221.5	-126.5	4.5	-90.5
30 km	-209.0	-1.0	59.0	-218	-124	2.0	-93.0
50 km	-205.0	-3.0	63.0	-215	-120	-2.0	-97.0

* Negative margin indicates the protection level criterion is exceeded

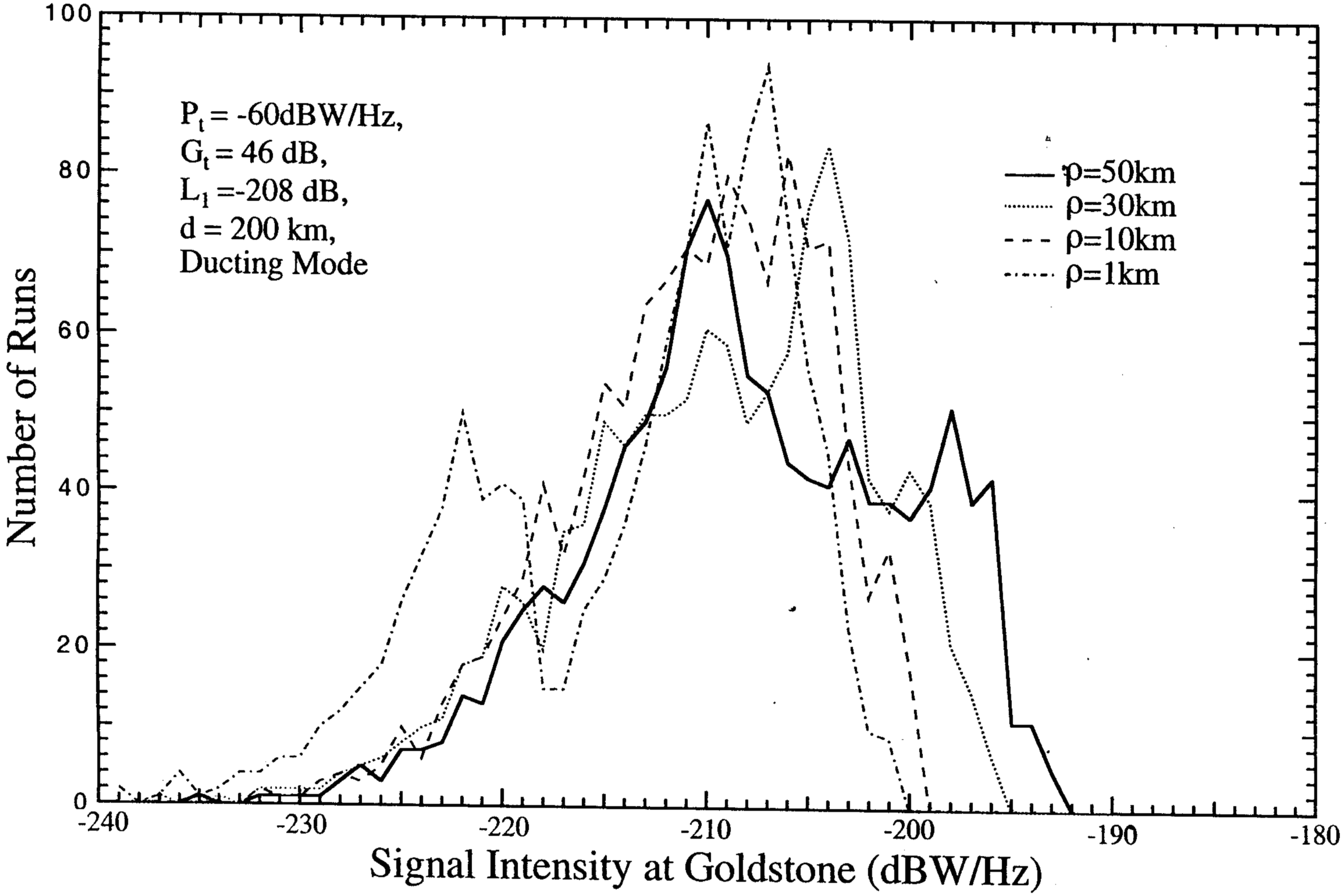


Figure 8. Interference signal intensities at Goldstone for different HDFS extended radius. Each curve shows the signal intensity distribution from 1200 HDFS deployment patterns. Only ducting transmission loss over a 200 km distance is considered here. In general, when the HDFS extended radius increases, the signal intensities shift to higher values.

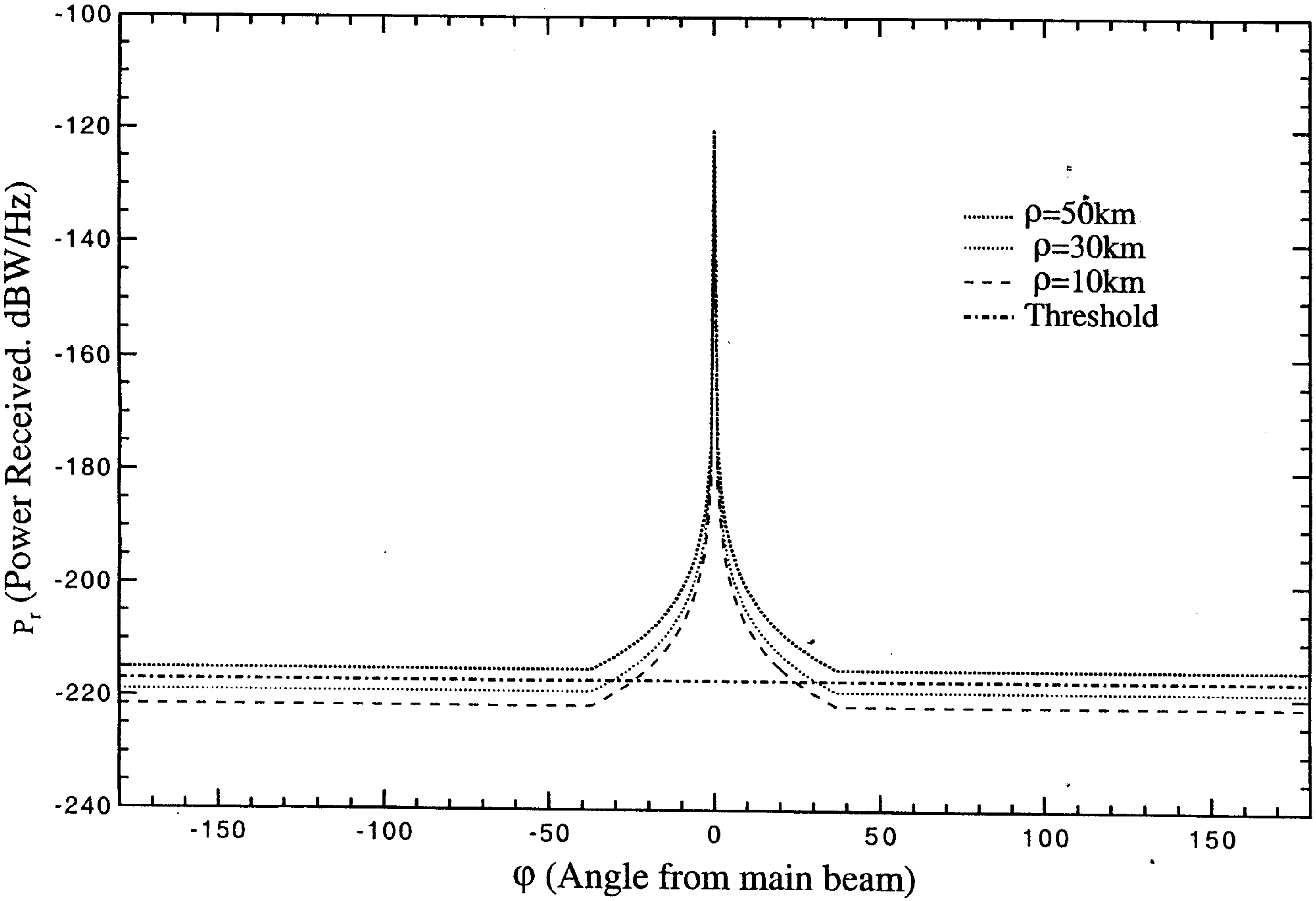


Figure 9. Received interference powers at Goldstone after the DSN receiver antenna gain in all azimuthal angles. Three curves correspond to signals from transmitters with different extended radius. As a reference, the DSN receiver threshold level is also shown. When the radius is greater than 30 km, the threshold is exceeded.

Summary

1. A thorough literature search was conducted for all ITU documents related to trans-horizon propagation interference effects and all HDFS operating parameters. Interference from a single transmitter through ducting, rain scattering and diffraction have been fully investigated. Aggregated interference effects from HDFS transmitter spatial distributions have been assessed using a simulation technique for the first time.

2. Worst-case estimates were performed for a single transmitter with the highest power level in the Los Angeles area and the cities near Goldstone. At a 200 km separation distance, when the transmitter's mainbeam is exactly pointed to the DSN antenna, only small positive margins can be expected relative to the backlobe of the receiver antenna for 0.001% of the time (weather condition). For some cities with distances less than 200 km, interference signals will largely exceed the threshold of the receiver.

3. Monte Carlo simulations were conducted to examine the interference effects on Goldstone tracking station using 3000 HDFS transmitters in the Los Angeles area. The impact of HDFS EIRP levels, spatial distributions and maximum radial distances have been examined. Preliminary statistical results for aggregated power distributions from 1200 trials with different maximum radial distances of the HDFS distributions were obtained. The results show that when the HDFS transmitter spatial distributions have large radial distances, aggregated transmitter antenna gains and interference power received at Goldstone are much greater than those calculated from a Normal distribution. When the radial distance is 50 km, the DSN receiver interference threshold will be exceeded.

4. We have developed an approach to quantitatively study the interference effect of HDFS transmitters with various orientations and distributions on the DSN, using a Monte Carlo simulation. As a future study, actual HDFS distributions can be simulated more realistically, and any proposed HDFS deployment patterns to mitigate the interference effects, such as coordinated (planned) antenna pointing, can be examined using this simulation tool. This tool can be also used to estimated potential interference to the DSN from other trans-horizon terrestrial services.