Project I

Design of Terrestrial Line-Of-Sight Link based on ITU-R Rec. P.530-18

Introduction

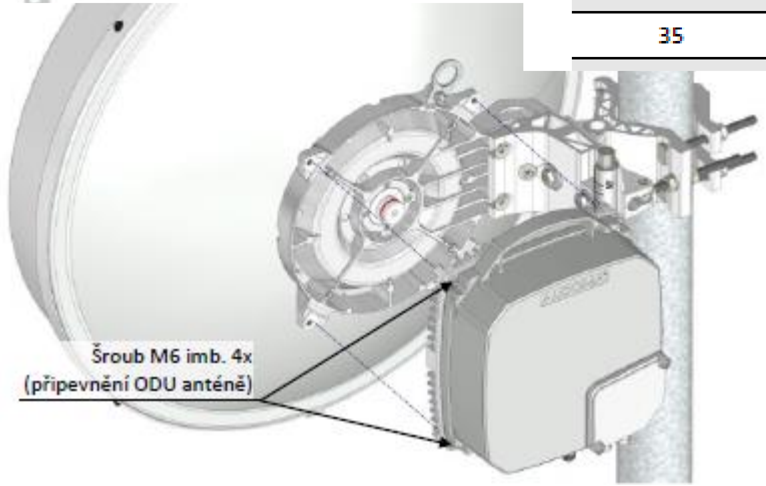
ITU-R P.530 Propagation data and prediction methods required for the design of terrestrial line-of-sight systems

- Step-by-step prediction methods for the relevant propagation effects.
- Other information and techniques that can be recommended in the planning of terrestrial line-of-sight systems.
- Effects on the wanted signal only (with the exception of the interference resulting from reduction in XPD).
- Propagation effects considered in the design of line-of-sight radio-relay systems:
  - diffraction fading due to obstruction of the path by terrain obstacles under adverse propagation conditions;
  - attenuation due to atmospheric gases;
  - fading due to atmospheric multipath or beam spreading (commonly referred to as defocusing) associated with abnormal refractive layers;
  - fading due to multipath arising from surface reflection;
  - attenuation due to precipitation or solid particles in the atmosphere;
  - variation of the angle-of-arrival at the receiver terminal and angle-of-launch at the transmitter terminal due to refraction;
  - reduction in cross-polarization discrimination (XPD) in multipath or precipitation conditions;
  - signal distortion due to frequency selective fading and delay during multipath propagation.

- Semi-empirical iterative approach
- Availability up to 99.999 % of time
- Outputs
  - antenna heights
  - fading/enhancement statistics, depolarization
  - + diversity and other fading mitigation techniques, multi-hop links, outage…

Parametr		AL17F MP600/360/165
Kmitočet vysílače MP600	- dolní část pásma (/A) - horní část pásma (/B)	17 100 ÷ 17 195 MHz 17 205 ÷ 17 300 MHz
Kmitočet vysílače MP360/165	- dolní část pásma (/A) - horní část pásma (/B	17 100 ÷ 17 160 MHz 17 240 ÷ 17 300 MHz
Minimální ladicí krok kanálování		200 kHz
Rozteč kanálů		viz tabulka 14 až tabulka 15
Stabilita kmitočtu lepší než		$\pm 10 \times 10^{-6}$
Vysílaný výkon základní varianty		viz tabulka 19, ATPC[3]
Maska spektra vysílače		ETSI 302 217-2-2
Typická prahová citlivost přijímače při BER = 10^{-6}		viz tabulka 19
Maximální provozní úroveň přijímaného signálu BER=10^{-6}		-19 dBm / -22 dBm[4]
Maximální úroveň přijímaného signálu nedestruktivní		-3 dBm

Celková bitová rychlost [Mbit/s]	Modulace	MP165 typická prahová citlivost pro BER = 10^{-6} [dBm]	MP360 typická prahová citlivost pro BER = 10^{-6} [dBm]	Vysílaný výkon [dB]	Šířka přenášeného spektra [MHz]
10	QPSK	-96,0	-93,5	-24 — 8	7
19	16 QAM	-87,0	-87,5	-24 — 8	
25	32 QAM	-83,0	-83,0	-24 — 8	
30	64 QAM	—	-89,0	-24 — 5	
35	128 QAM	—	-75,0	-24 — 5	

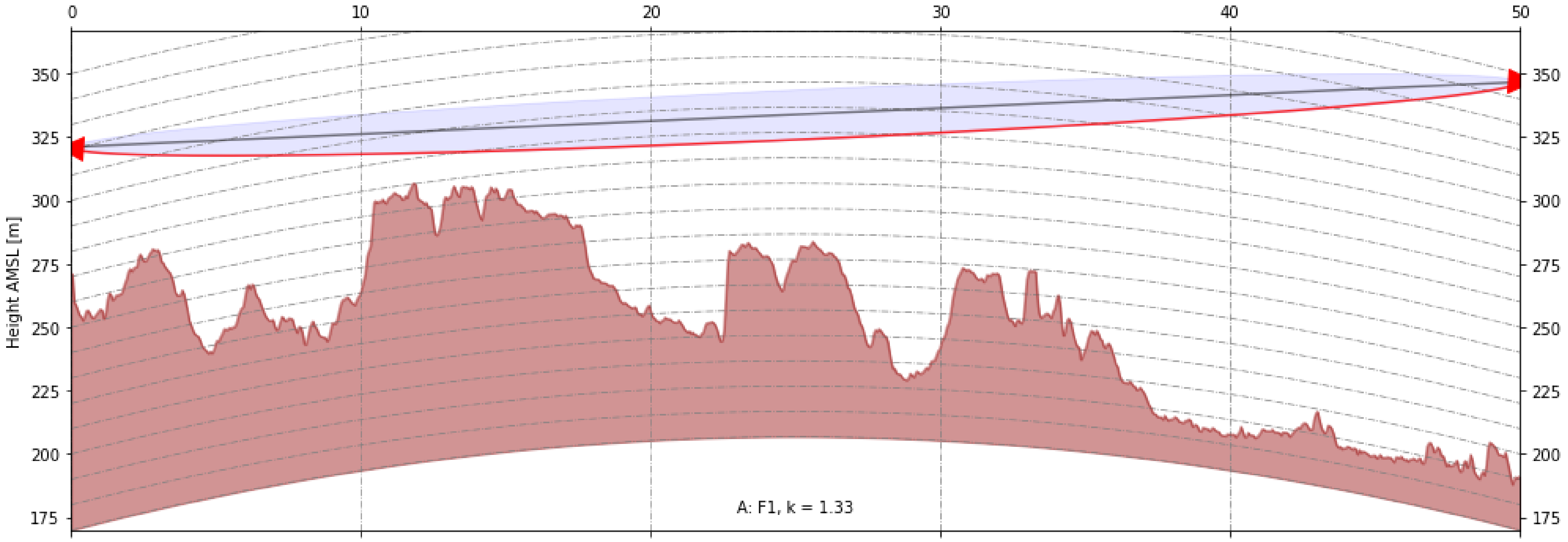


http://www.alcoma.cz/index.php
http://www.al-wireless.com/alxxf

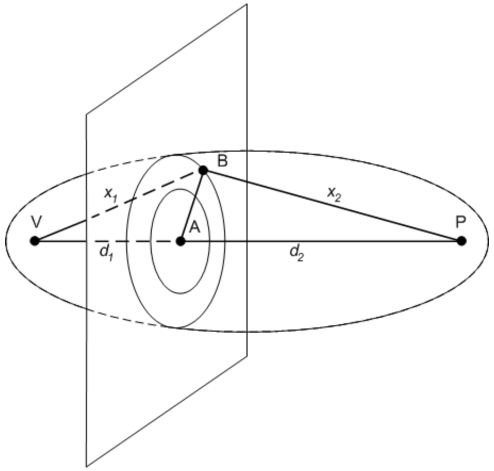
P.530 (2.2.2) Planning criteria for path clearance

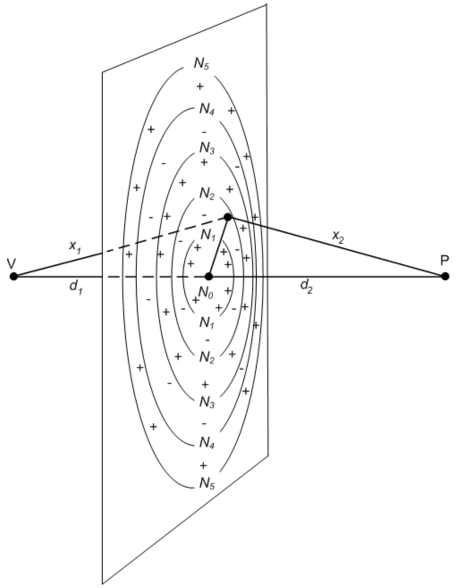
2.2.2.1 Non-diversity antenna configurations

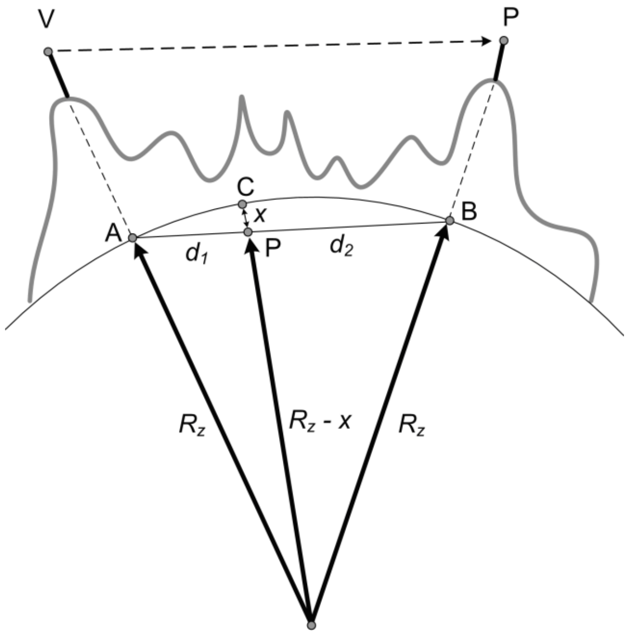
Step 1: Determine the antenna heights required for the appropriate median value of the point k-factor (see § 2.2; in the absence of any data, use $k = 4/3$) and 1.0 F_1 clearance over the highest obstacle (temperate and tropical climates).



Recall







$$(x_1 + x_2) - (d_1 + d_2) = \mathrm{n}\frac{\lambda}{2}$$

$$\sqrt{d_1^2 + b_\mathrm{n}^2} + \sqrt{d_2^2 + b_\mathrm{n}^2} - d_1 - d_2 = \mathrm{n}\frac{\lambda}{2}$$

$$\sqrt{d_{1,2}^2 + b_\mathrm{n}^2} \approx d_{1,2} + \frac{b_\mathrm{n}^2}{2d_{1,2}}$$

$$b_\mathrm{n} = \sqrt{\frac{d_1 d_2 n\lambda}{d_1 + d_2}}$$

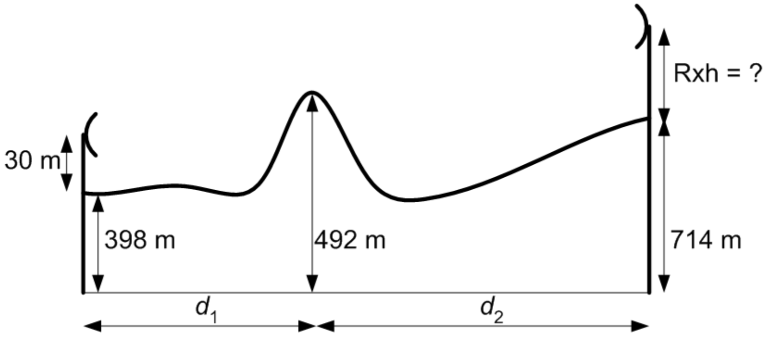
$$R_e = k_e R_Z$$

$$d_1 \cdot d_2 = x \cdot (2R_e - x) \approx x2R_e$$

$$x = \frac{d_1 d_2}{2R_e}$$

Path Clearance - Example

f = 6.175 GHz
d_1 = 17 km
d_2 = 29.38 km
h_o = 492 m (amsl)
$d = d_1 + d_2$ = 46.38 km



Recall: $$b_n = \sqrt{\frac{d_1 d_2 n\lambda}{d_1 + d_2}} \qquad x = \frac{d_1 d_2}{2R_e}$$

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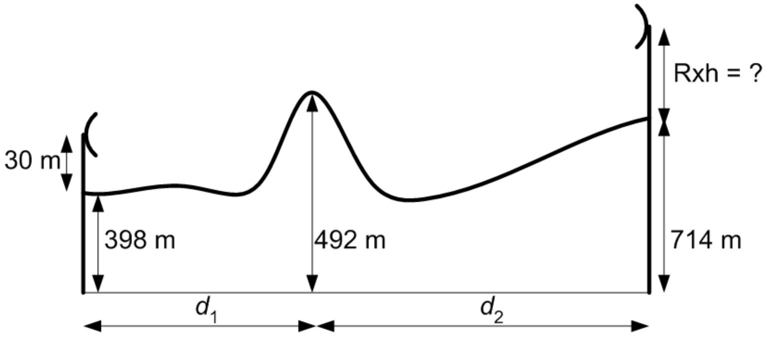

$$F_1 = 17.3\sqrt{\frac{d_1 d_2}{fd}} = 17.3\sqrt{\frac{17 \cdot 29.38}{6.175 \cdot 46.38}} = 22.8 \text{ m}$$

$$R_e = \frac{4}{3} 6371 \approx 8500 \text{ km}$$

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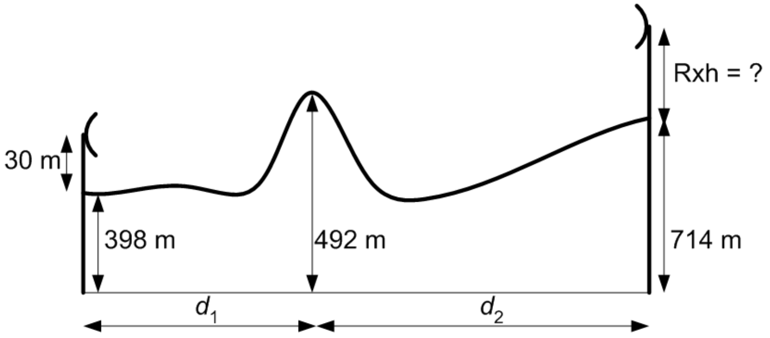

$$F_1 = 17.3\sqrt{\frac{d_1 d_2}{fd}} = 17.3\sqrt{\frac{17 \cdot 29.38}{6.175 \cdot 46.38}} = 22.8 \text{ m}$$

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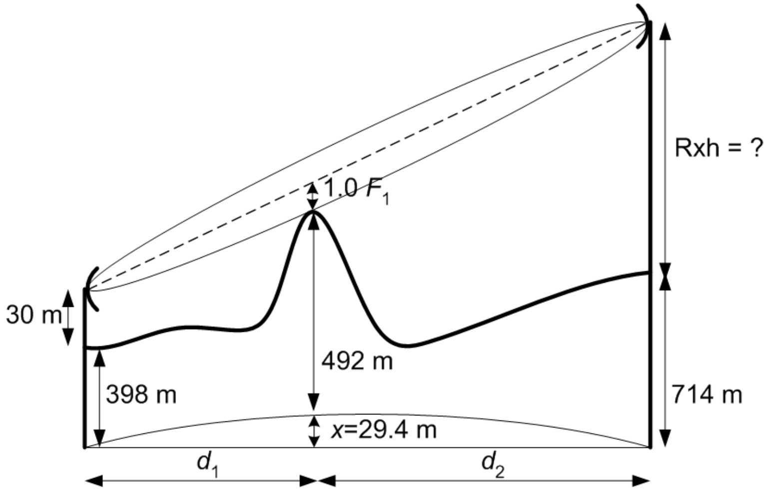


$$x = \frac{d_1 d_2}{2R_e} = \frac{17000 \cdot 29380}{2 \cdot 8500000} = 29.4 \text{ m}$$

$$\frac{h_2 - h_1}{d} = \frac{(x + h_o + F_1) - h_1}{d_1}$$

$$\frac{Rxh + 714 - (398 + 30)}{46380} = \frac{29.4 + 492 + 22.8 - (398 + 30)}{17000}$$

***Rxh* = 31.0 m**

P.530 (2.2.2) Planning criteria for path clearance

Step 2: Obtain the value of k_e from Fig. 2 for the path length in question, d, or from:

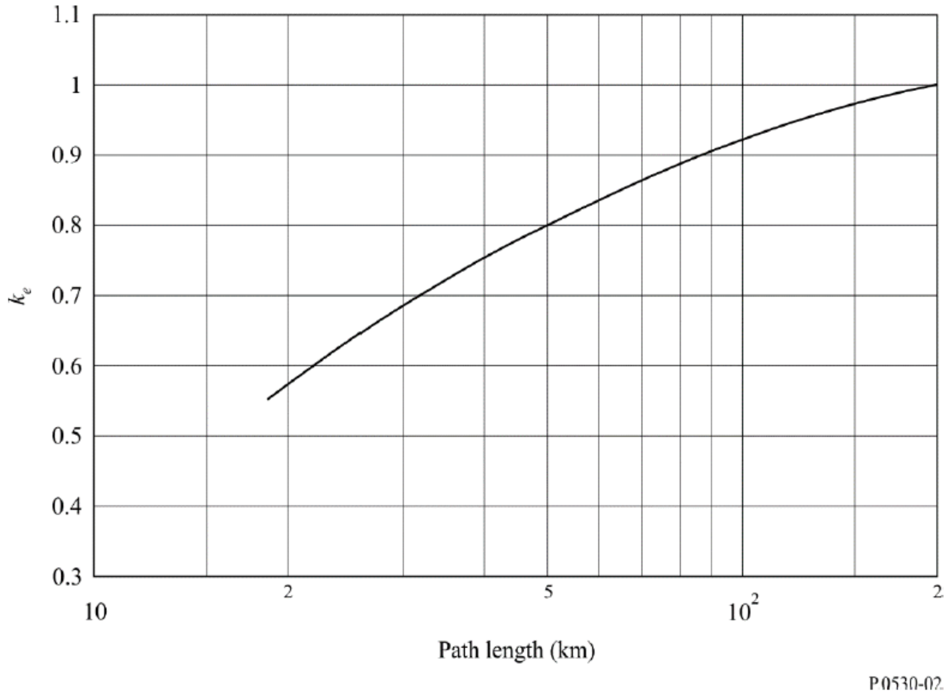
$$k_e = \frac{157}{144 + {}^{2670}/_{d}}$$

Step 3: Calculate the antenna heights required for the value of k_e obtained from Step 2 and the following Fresnel zone clearance radii:

Temperate climate	Tropical climate
0.0 F_1 (i.e. grazing) if there is a single isolated path obstruction 0.3 F_1 if the path obstruction is extended along a portion of the path	0.6 F1 for path lengths greater than about 30 km

FIGURE 2

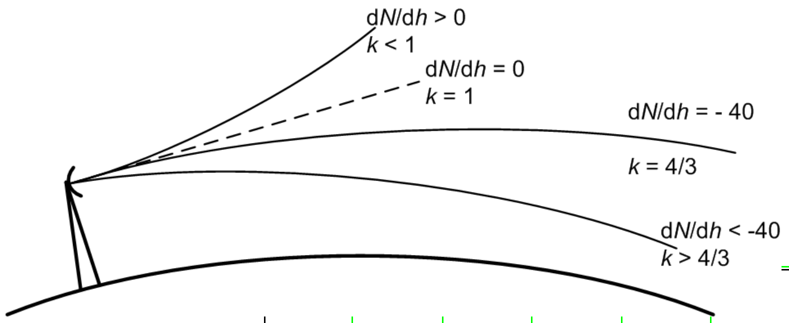
Value of k_e exceeded for approximately 99.9% of the worst month (continental temperate climate)

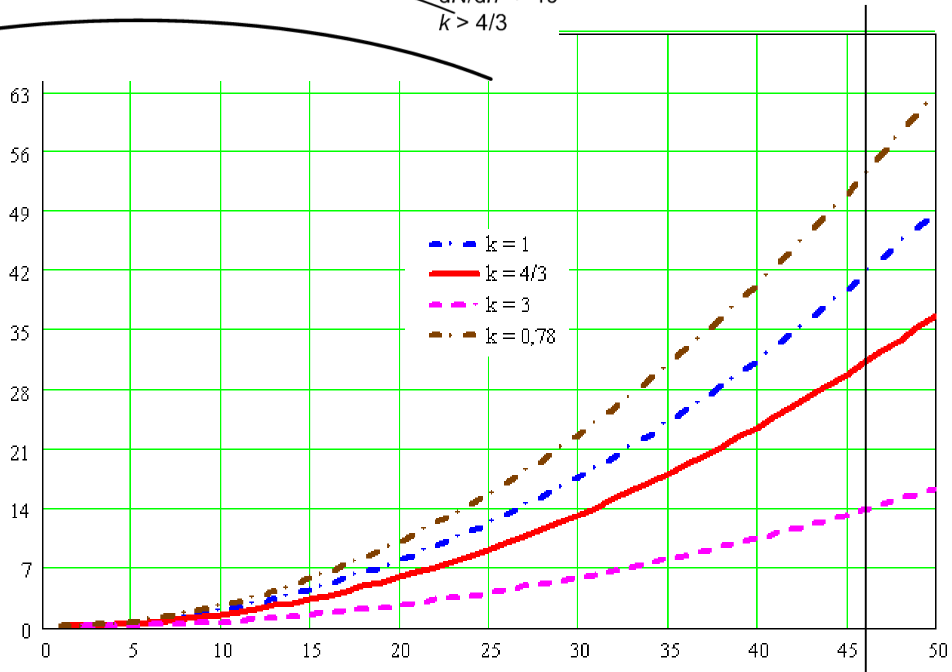


Step 4: Use the larger of the antenna heights obtained by Steps 1 and 3 (see Note 1).

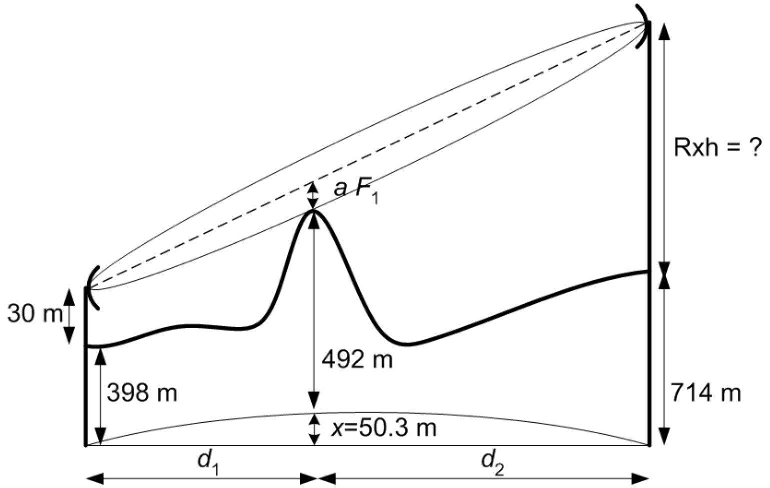
NOTE 1 – Although these rules are conservative from the viewpoint of diffraction loss due to sub-refractive fading, it must be made clear that an overemphasis on minimizing unavailability due to diffraction loss in sub-refractive conditions may result in a worse degradation of performance and availability in multipath conditions. It is not currently possible to give general criteria for the trade-off to be made between the two conditions. Among the relevant factors are the system fading margins available.

(2.2.2.2 Two or three antenna space-diversity configurations …)





$$x = \frac{d_1 d_2}{2R_z}$$



$k_e = 0.78$

$R_e = k_e \cdot R_e = 0.78 \cdot 6371 = 4969$ km

$x = (d_1 \cdot d_2)/(2R_e) = 50.3$ m

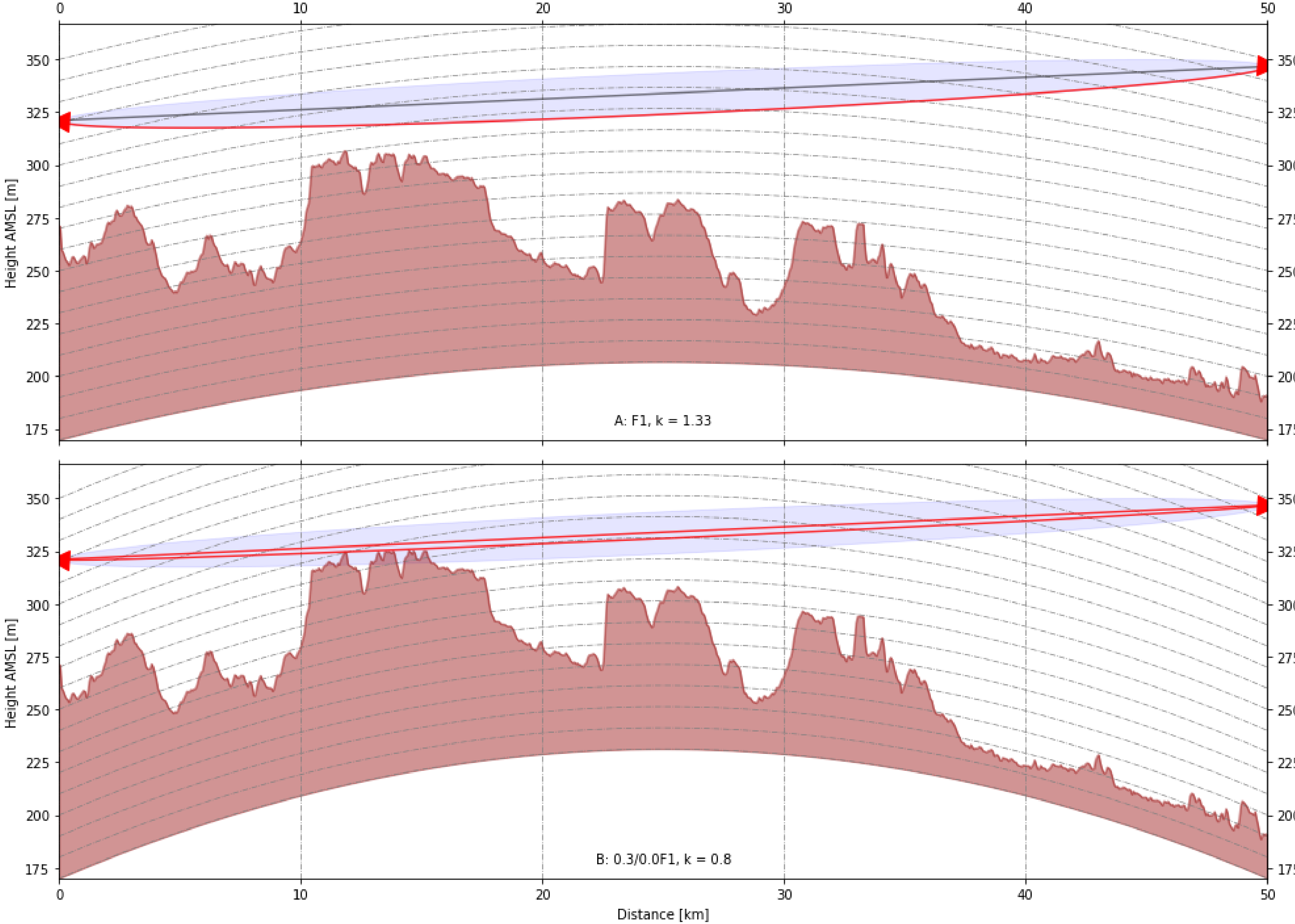
a=0 if there is a single isolated path obstruction
a=0.3 if the path obstruction is extended along a portion of the path
a= 0.6 for path lengths greater than about 30 km

$d = 46.38$ km

$k_e = 0.78$

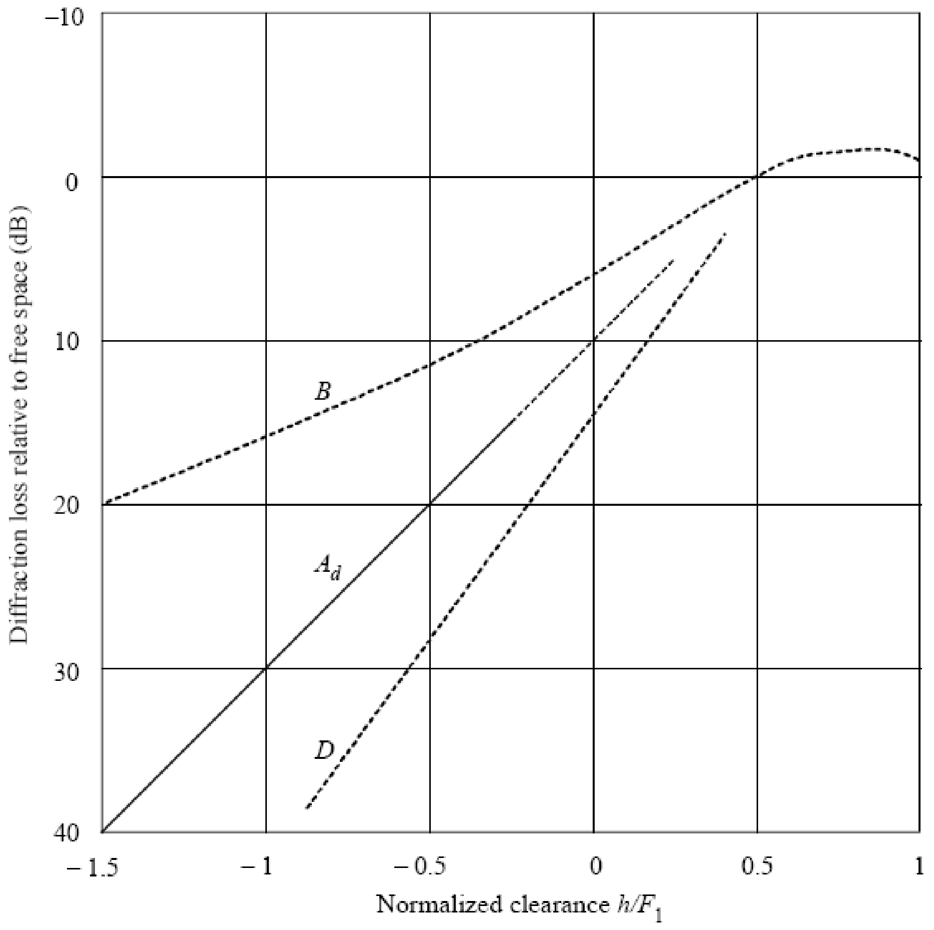
$R_{xh} = 25.7$ m ($a = 0$)

$$\mathbf{h_r = \max(30.0\ m, 25.7\ m) = 30.0\ m}$$


Height AMSL [m]
Distance [km]
A: F1, k = 1.33
B: 0.3/0.0F1, k = 0.8
0
10
20
30
40
50
175
200
225
250
275
300
325
350

P.530 Diffraction loss

Diffraction loss for obstructed line-of-sight microwave radio paths



B: theoretical knife-edge loss curve
D: theoretical smooth spherical Earth loss curve, at 6.5 GHz and $k_e = 4/3$
A_d: empirical diffraction loss based on equation (2) for intermediate terrain
h: amount by which the radio path clears the Earth's surface
F_1: radius of the first Fresnel zone

0530-01

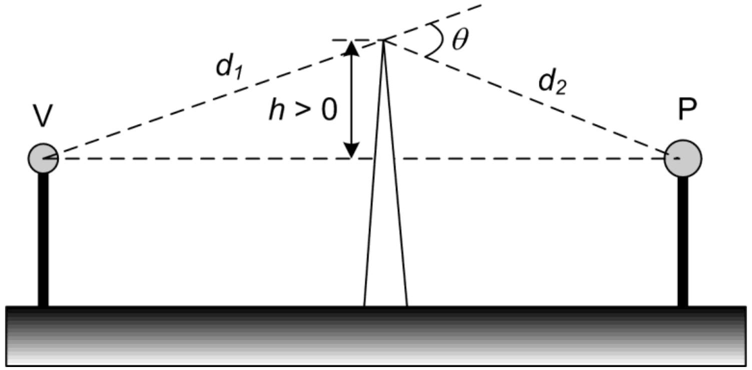
$$A_d = -20\, h / F_1 + 10 \qquad \text{dB}$$

$$F_1 = b_1 = 17.3 \sqrt{\frac{d_1 d_2}{f\ d}} \quad \text{m}$$

d in km
f in GHz

$$\frac{h}{b_1} = \frac{\nu}{\sqrt{2}}$$

$$\nu = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1} + \frac{1}{d_2}\right)} = \theta \sqrt{\frac{2}{\lambda\left(\frac{1}{d_1} + \frac{1}{d_2}\right)}}$$

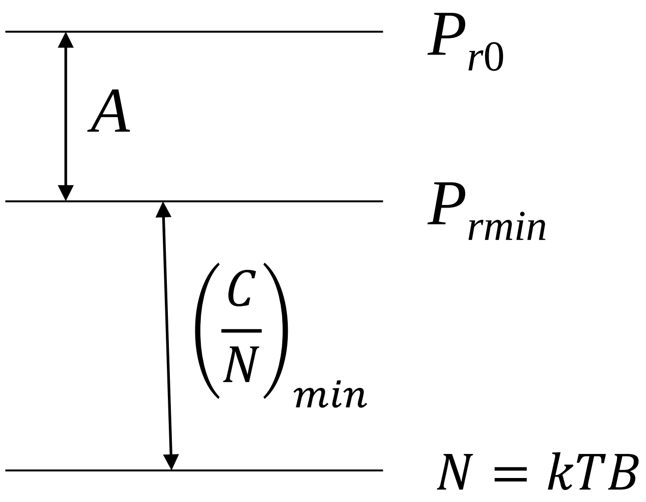


Power Budget / Fade Margin

$$P_{r0} = P_t + G_t + G_r - FSL - L_{gas} - L_{diff} - L_{sys}$$

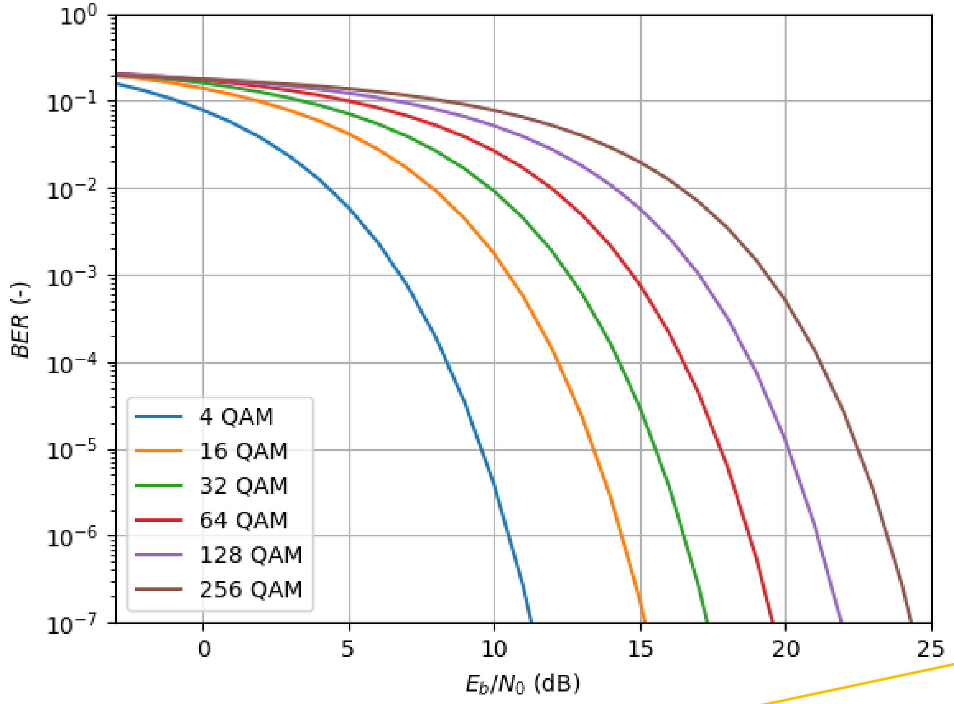
$$P_r = P_{r0} - L_{fade} > P_{rmin}$$

fade margin ***A*** receiver sensitivity



- fading due to atmospheric multipath or beam spreading (commonly referred to as defocusing) associated with abnormal refractive layers;
- fading due to multipath arising from surface reflection;
- attenuation due to precipitation or solid particles in the atmosphere;
- variation of the angle-of-arrival at the receiver terminal and angle-of-launch at the transmitter terminal due to refraction;
- reduction in cross-polarization discrimination (XPD) in multipath or precipitation conditions;
- signal distortion due to frequency selective fading and delay during multipath propagation.

Receiver sensitivity



$$\frac{C}{N} = \frac{E_b}{N_0}\frac{f_b}{B}$$

$$N = kTB$$

$$P_{rmin} = \frac{C}{N}N$$

	QPSK	16 QAM	32 QAM	64 QAM	128 QAM	256 QAM
BER10^{-6}	10.8 dB	14.7 dB	16.8 dB	18.9 dB	21.3 dB	23.8 dB

Mikrovlnný datový spoj AL24F MP165

ALCOMA

7.2 MODULACE, PRAHOVÉ CITLIVOSTI A PŘENOSOVÉ KAPACITY SPOJE

Spoj AL24F MP165 lze nastavit na různé přenosové kapacity podle použité modulace a šířky kanálu. Jednotlivé přenosové kapacity jsou spjaty s různou prahovou citlivostí, viz. tabulka 11.

Nejvyšší interní přenosová rychlost spoje včetně obslužné komunikace spoje je 165 Mbit/s.

Celková bitová rychlost [Mbit/s]	Modulace	Typická prahová citlivost pro BER = 10^{-6} [dBm]	Šířka přenášeného spektra [MHz]
10	QPSK	-92	7
19	16	-87	
25	32	-83	
17	QPSK	-88	14
39	16 QAM	-84	
50	32 QAM	-80	
61	64 QAM	-77	
72	128 QAM	-72	
34	QPSK	-87	28
77	16 QAM	-80	
100	32 QAM	-77	
123	64 QAM	-75	
158	128 QAM	-70	
165[3]	128 QAM	-69	

Tabulka 11 Přenosové rychlosti spoje

Example:

$$P_{rmin} = \frac{C}{N}N = \frac{E_b}{N_0}\frac{f_b}{B}kTB = 10^{\frac{16.8}{10}}\, 50 \cdot 10^6 \cdot 1.38 \cdot 10^{-23} \cdot 290 =$$

$$= 9.6\ \text{pW} \equiv -80.2\ \text{dBm}$$

C/N - carrier to noise ratio (-)
N - noise power (W)
K - Boltzmann's constant 1.38*10^{-23} J/K
T - temperature (K)
E_b/N_0 - energy per bit to noise power spectral density ratio (-)
f_b - data rate (bit/s)
B - channel bandwidth (Hz)

Relations between $\frac{C}{N}, \frac{E_b}{N_0}, f_b, B$ are given by the specific channel, hardware and signal processing.

ALCOMA

7.3 TECHNICKÉ PARAMETRY

Parametr		AL24F MP165
Kmitočet vysílače	- dolní část pásma (/A)	24 000 ÷ 24 060 MHz
	- horní část pásma (/B)	24 190 ÷ 24 250 MHz
Minimální ladicí krok kanálování		50 kHz
Rozteč kanálů		viz tabulka 9
Stabilita kmitočtu lepší než		$\pm 10 \times 10^{-6}$
Vysílaný výkon základní varianty		max. 5 dBm ATPC[4]
Maska spektra vysílače		ETSI 301 751
Typ		
(ma		
Uži		
Vol		
Vst		
Spo		
(do		
Ma		
Ste		
Na		

Kompaktní mikrovlnné antény	Typ			
	AL1-24/ME	AL2-24/ME	AL3-24/MP	AL4-24/MP
Průměr paraboly	Ø 0,35 m	Ø 0,65 m	Ø 0,90 m	Ø 1,20 m
Zisk antény G_{ant}	36 dB	41 dB	45 dB	47 dB
Hlavní lalok 3 dB	±1,3°	±0,75°	±0,5°	±0,4°
Horizontální nastavení antény	± 180°		±7°	
Vertikální nastavení antény	±25°	±25°	±15°[6]	±15°[6]
Hmotnost kompaktních antén	5,6 kg	8,3 kg	26 kg	36 kg
Průměr montážního stojanu[7] min.	Ø 38 mm	Ø 48 mm	Ø 73 mm	Ø 101 mm
max.	Ø 115 mm			

Tabulka 15 Parametry antén ME, MP

Mikrovlnný datový spoj AL24F MP165

ALC

7.2 MODULACE, PRAHOVÉ CITLIVOSTI A PŘENOSOVÉ KAPACITY SPOJE

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50	32 QAM	-80	
61	64 QAM	-77	
72	128 QAM	-72	
34	QPSK	-87	28
77	16 QAM	-80	
100	32 QAM	-77	
123	64 QAM	-75	

Example

frequency = 6.175 GHz

Tx location [49.93833, 14.35778]
Tx antenna height 398 + 30 = 428 m amsl
Tx power Pt = 29 dBm
Tx antenna gain Gt = 38.2 dBi

Rx location [49.53750, 14.51056]
Rx antenna height 714 + 31 = 745 m amsl
Rx sensitivity for BER = 10^{-3} / 10^{-6}:
Pr_BER_3 = –71 dBm
Pr_BER_6 = –66 dBm
Rx antenna gain Gr = 38.2 dBi

Other system losses = 9.5 dB

Path length 46.38 km
FSL = 141.54 dB

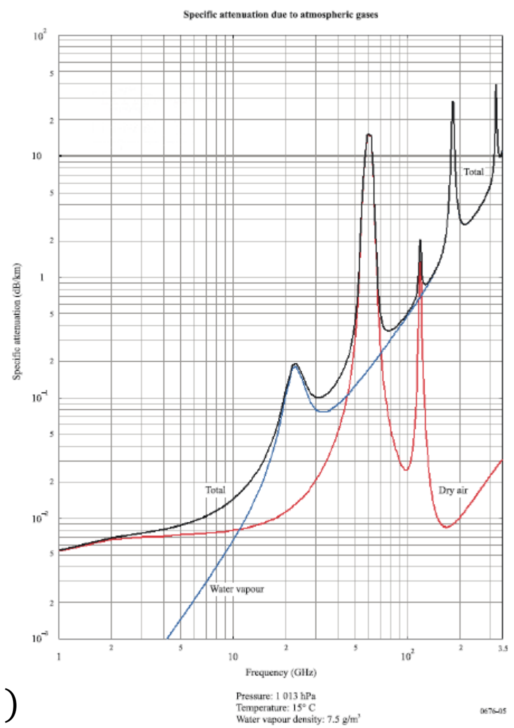
2.1 Attenuation due to atmospheric gases

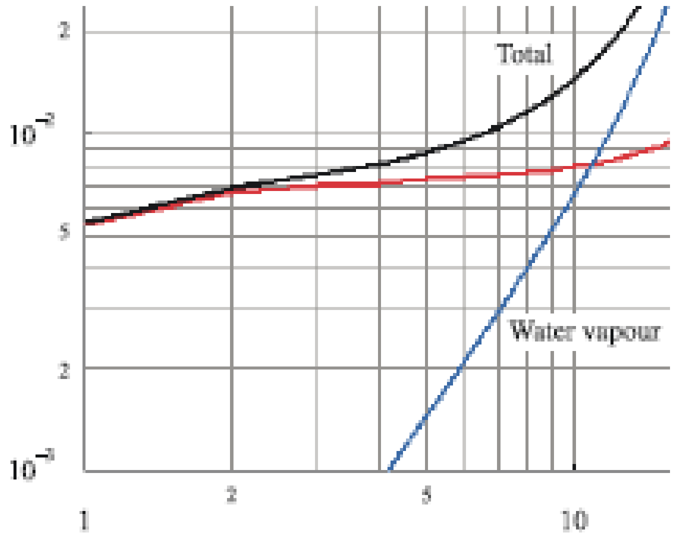
Some attenuation due to absorption by oxygen and water vapour is always present, and should be included in the calculation of total propagation loss at frequencies above about 10 GHz. The attenuation on a path of length d (km) is given by:

$$A_a = \gamma_a \, d \qquad \text{dB} \tag{1}$$

The specific attenuation γ_a (dB/km) should be obtained using Recommendation ITU-R P.676.

NOTE 1 – On long paths at frequencies above about 20 GHz, it may be desirable to take into account known statistics of water vapour density and temperature in the vicinity of the path. Information on water vapour density is given in Recommendation ITU-R P.836.





A_a = 0.097 dB/km · 46.38 km = 0.45 dB

$d = R_Z \arccos(\cos\theta_1 \cos\theta_2 \cos(\lambda_1 - \lambda_2) + \sin\theta_1 \sin\theta_2 \quad)$
θ ... latitude, λ ... longitude

Fading (P.530)

Clear air / No fading: L_clear_air = FSL + L_gas + L_diffraction = 141.54 + 0.45 + 0 = 141.99

margin_BER6 = Pt – Pr_BER_6 + Gt + Gr – L_sys – L_clear_air =
= 29 – (– 66) + 38.2 + 38.2 – 9.5 – 142.0 = 19.9 dB

margin_BER3 = Pt – Pr_BER_3 + Gt + Gr – L_sys – L_clear_air =
= 29 – (– 71) + 38.2 + 38.2 – 9.5 – 142.0 = 24.9 dB

- Outage probability
  - *Clear air effects* $P_t = P_{ns} + P_s + P_{XP}$ (no diversity)
    - non-selective (flat) fading – multipath and related mechanisms
    - frequency selective (distortion)
    - XPD outage (depolarisation)
  - *Precipitation* $P_{tr} = P_{rain} + P_{XPR}$
    - Absorption (attenuation due to hydrometeors)
    - XPD outage (depolarisation)
- Simultaneous fading on multi-hop links
- Diversity
- Techniques to reduce fading

2.3 Fading and enhancement due to multipath and related mechanisms

Various clear-air fading mechanisms caused by extremely refractive layers in the atmosphere must be taken into account in the planning of links of more than a few kilometres in length; beam spreading (commonly referred to as defocusing), antenna decoupling, surface multipath, and atmospheric multipath. Most of these mechanisms can occur by themselves or in combination with each other (see Note 1). A particularly severe form of frequency selective fading occurs when beam spreading of the direct signal combines with a surface reflected signal to produce multipath fading. Scintillation fading due to smaller scale turbulent irregularities in the atmosphere is always present with these mechanisms but at frequencies below about 40 GHz its effect on the overall fading distribution is not significant.

A method for predicting the single-frequency (or narrow-band) fading distribution at large fade depths in the average worst month in any part of the world is given in § 2.3.1. This method does not make use of the path profile and can be used for initial planning, licensing, or design purposes. A second method in § 2.3.2 that is suitable for all fade depths employs the method for large fade depths and an interpolation procedure for small fade depths.

2.3.1 Method for small percentages of time

Multipath fading and enhancement only need to be calculated for path lengths longer than 5 km, and can be set to zero for shorter paths.

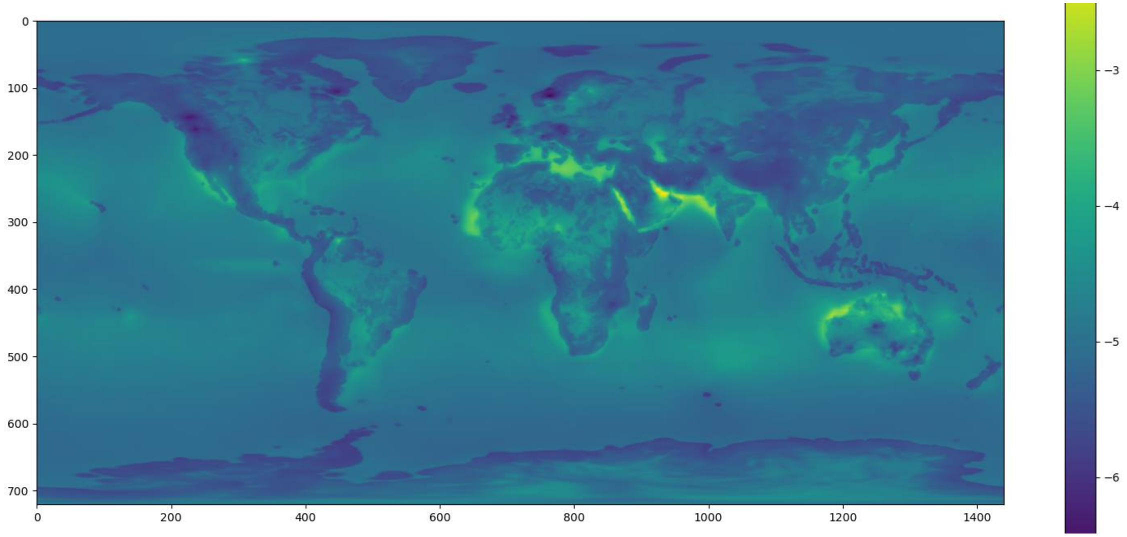
Step 1: For the path location in question, estimate the geoclimatic factor K for the average worst month from fading data for the geographic area of interest if these are available (see Attachment 1).

K = 8.73e-07 %

If measured data for K are not available, estimate the geoclimatic factor for the average worst month by the antilog of the bilinear interpolation of the four closest grid points of the table LogK.csv integral to this Recommendation, which is the base 10 logarithm of K %.

1.1 Integral digital products

Only the file versions provided with this Recommendation should be used. They are an integral part of the Recommendation. Table 1 gives details of the digital products used in the method. Interpolation of LogK.csv and dN75.csv for path centre coordinates is performed by bilinear interpolation, described in Recommendation ITU-R P.1144. The files LatitudeQuarterDegree.csv and LongitudeQuarterDegree.csv are provided for convenience in performing the interpolation (see R-REC-P.530-18-202109-I!!ZIP-E.zip).



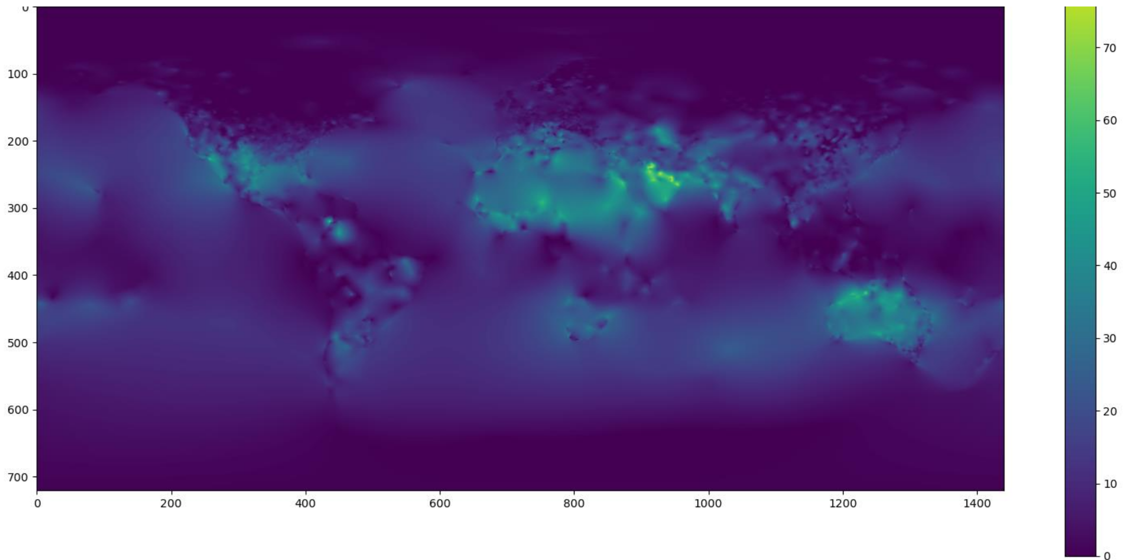


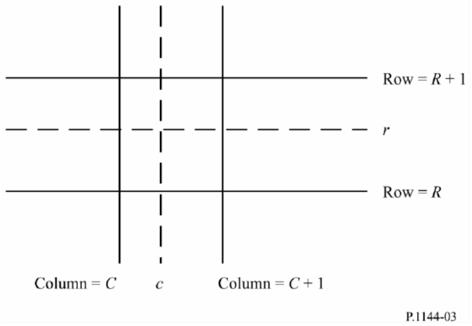
TABLE 1

Digital products

Filename	Ref.	Origin	Latitude (rows)			Longitude (columns)		
			First row (°N)	Spacing (degrees)	Number of rows	First col (°W)	Spacing (degrees)	Number of cols
LogK.csv	§ 2.3.1	P.530	90	0.25	721	180	0.25	1441
dN75.csv	§ 2.3.1	P.530	90	0.25	721	180	0.25	1441
LatitudeQuarterDegree.csv	§ 2.3.1	P.530	90	0.25	721	180	0.25	1441
LongitudeQuarterDegree.csv	§ 2.3.1	P.530	90	0.25	721	180	0.25	1441

1b Bi-linear interpolation on a square grid

FIGURE 3



LogK = –6.059

K = 8.73 e –7 %

dN75 = 2.93 N/75m

Step 2: From the antenna heights h_e and h_r ((m) above sea level), calculate the magnitude of the path inclination $|\varepsilon_p|$ (mrad) from:

$$|\varepsilon_p| = |h_r - h_e| \,/\, d \qquad (5)$$

where d is the path length (km), and the mean path terrain clearance h_c (m) from:

$$h_c = \frac{h_r + h_e}{2} - \frac{d^2}{102} - h_t \quad \text{m} \qquad (6)$$

where h_t is the mean terrain elevation (m above sea level) along the path, excluding trees.

(744 – 428)/46 = 6.8 mrad

(744 – 428)/2 – 46.38^2/102 – 535 = 30.4 m

Step 3: Calculate the percentage of time p_w that fade depth A (dB) is exceeded in the average worst month from:

$$p_w = Kd^{3.51}(f^2 + 13)^{0.447} \times 10^{-0.376tanh\left(\frac{h_c - 147}{125}\right) - 0.334|\varepsilon_p|^{0.39} - 0.00027h_L + 17.85v_{sr} - A/10} \quad \% \qquad (7)$$

where the subrefractive parameter v_{sr} is:

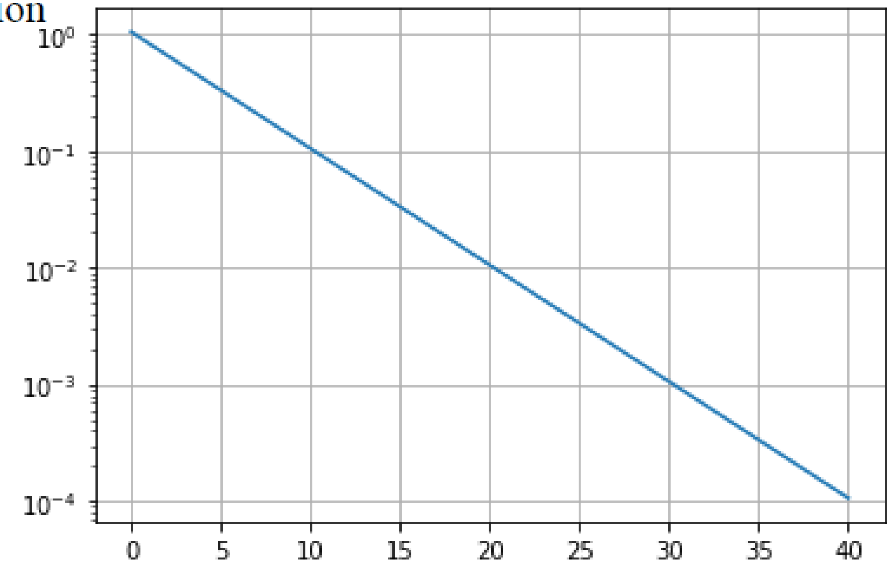
$$v_{sr} = \min\left\{\left(\frac{dN_{75}}{50}\right)^{1.8} \exp\left[-\frac{h_c}{2.5\sqrt{d}}\right], v_{srlimit}\right\} \qquad (8)$$

which has an upper limit for very low clearance paths, set by obstruction diffraction, given by:

$$v_{srlimit} = \frac{dN_{75} d^{1.5} f^{0.5}}{24730} \quad \text{m} \qquad (9)$$

Parameter dN_{75} is an empirical prediction of 0.1% of the average worst month refractivity increase with height over the lowest 75 m of the atmosphere from surface dewpoint data, found by bilinear interpolation of the four closest grid points of the table dN75.csv integral to this Recommendation. In some high latitude regions, $dN_{75} = 0$. Inclusion of v_{sr} in equation (7) represents median depression effects in general rather than classical linear gradient subrefractive path obstruction.

margin_BER6: A = 19.9 dB p_w = 0.01083 % P_{ns} = 1,083·10^{-4} (cca 1 h/year)
margin_BER3: A = 24.9 dB p_w = 0.00342 % P_{ns} = 3,425·10^{-5} (cca 20 min/year)



2.3.2 Method for all percentages of time

The method given below for predicting the percentage of time that any fade depth is exceeded combines the deep fading distribution given in the preceding section and an empirical interpolation procedure for shallow fading down to 0 dB.

Step 1: Using the method in § 2.3.1 calculate the multipath occurrence factor, p_0 (i.e. the intercept of the deep-fading distribution with the percentage of time-axis):

$$p_0 = K d^{3.51} (f^2 + 13)^{0.447} \times 10^{-0.376 tanh\left(\frac{h_{c-147}}{125}\right) -0.334|\varepsilon_p|^{0.39} -0.00027 h_L + 17.85 v_{sr}} \quad \% \qquad (11)$$

with K obtained from *Step 1* of § 2.3.1. Note that equation (11) is equivalent to equation (7) with $A = 0$.

Step 2: Calculate the value of fade depth, A_t, at which the transition occurs between the deep-fading distribution and the shallow-fading distribution as predicted by the empirical interpolation procedure:

$$A_t = 25 + 1.2 \log p_0 \qquad \text{dB} \qquad (12)$$

The procedure now depends on whether A is greater or less than A_t.

Step 3a: If the required fade depth, A, is equal to or greater than A_t:

Calculate the percentage of time that A is exceeded in the average worst month:

$$p_w = p_0 \times 10^{-A/10} \qquad \% \qquad (13)$$

Note that equation (13) is equivalent to equation (7).

Step 3b: If the required fade depth, A, is less than A_t:

....

$p_0 = p_w(A = 0) = 1.0583$ %

$A_t = 25$ dB

Step 3b: If the required fade depth, A, is less than A_t:

Calculate the percentage of time, p_t, that A_t is exceeded in the average worst month:

$$p_t = p_0 \times 10^{-A_t/10} \qquad \%$$

Note that equation (14) is equivalent to equation (7), with $A = A_t$.

Calculate q'_a from the transition fade A_t and transition percentage time p_t:

$$q'_a = -20 \log_{10}\left\{-\ln\left[\left(100 - p_t\right)/100\right]\right\}/A_t$$

Calculate q_t from q'_a and the transition fade A_t:

$$q_t = \left(q'_a - 2\right) \Big/ \left[\left(1 + 0.3 \times 10^{-A_t/20}\right) 10^{-0.016\,A_t}\right] - 4.3\left(10^{-A_t/20} + A_t/800\right) \qquad (16)$$

Calculate q_a from the required fade A:

$$q_a = 2 + \left[1 + 0.3 \times 10^{-A/20}\right]\left[10^{-0.016\,A}\right]\left[q_t + 4.3\left(10^{-A/20} + A/800\right)\right] \qquad (17)$$

Calculate the percentage of time, p_w, that the fade depth A (dB) is exceeded in the average worst month:

$$p_w = 100\left[1 - \exp\left(-10^{-q_a A/20}\right)\right] \qquad \% \qquad (18)$$

Provided that $p_0 < 2\,000$, the above procedure produces a monotonic variation of p_w versus A which can be used to find A for a given value of p_w using simple iteration.

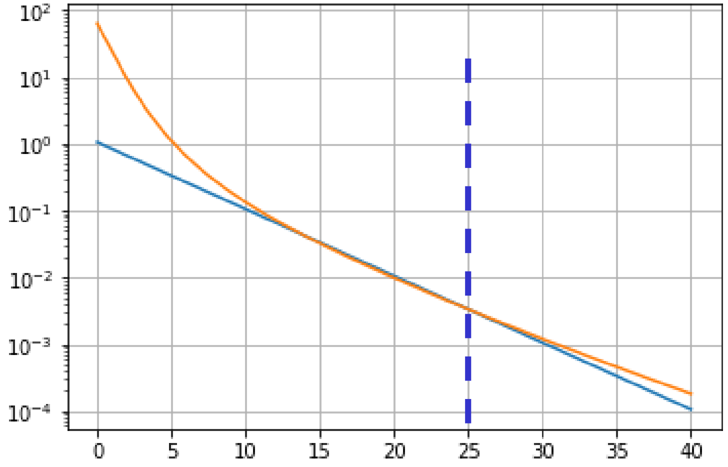
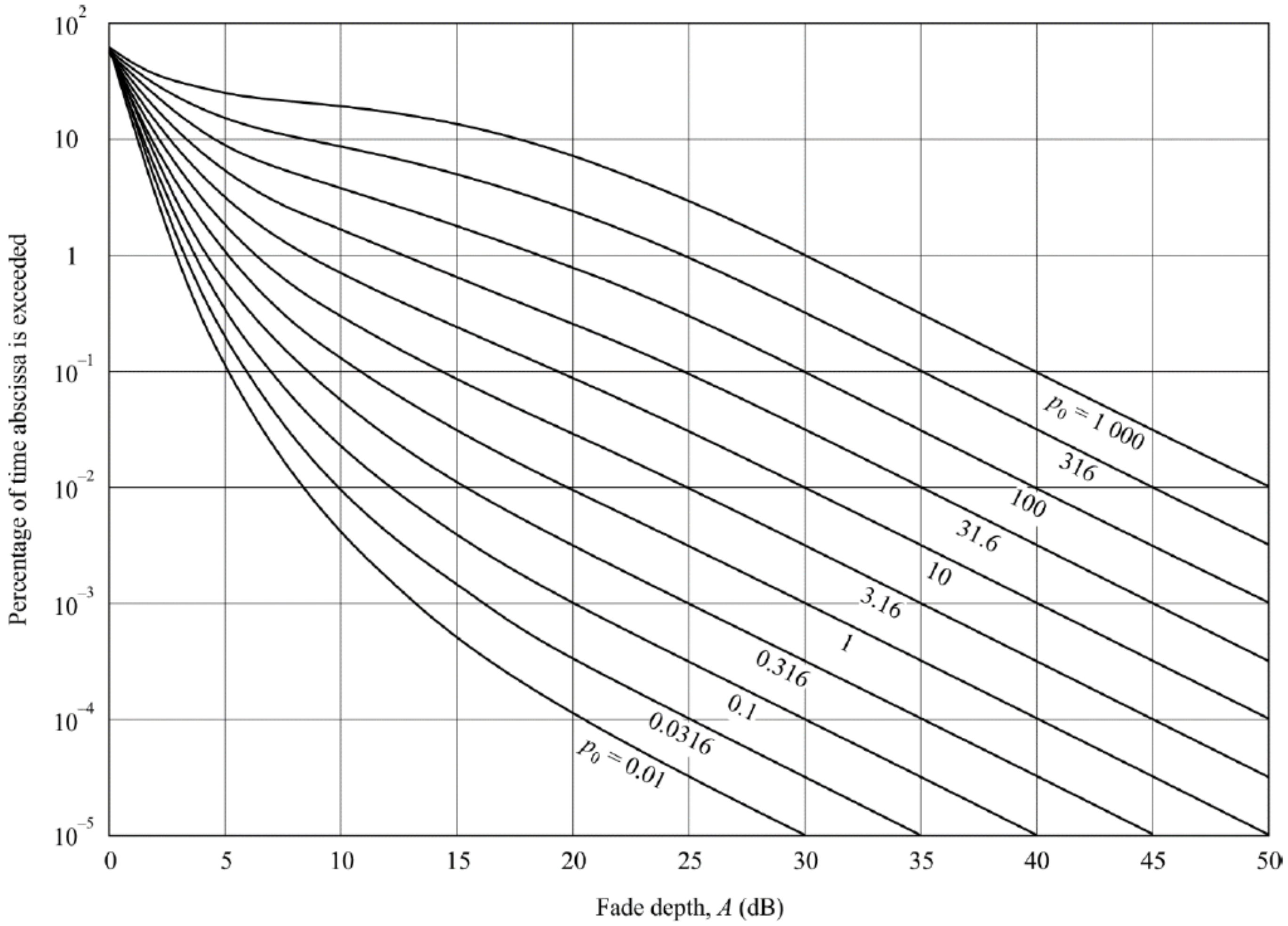


FIGURE 3

Percentage of time, p_w, fade depth, A, exceeded in average worst month, with p_0 (in equation (11)) ranging from 0.01 to 1 000



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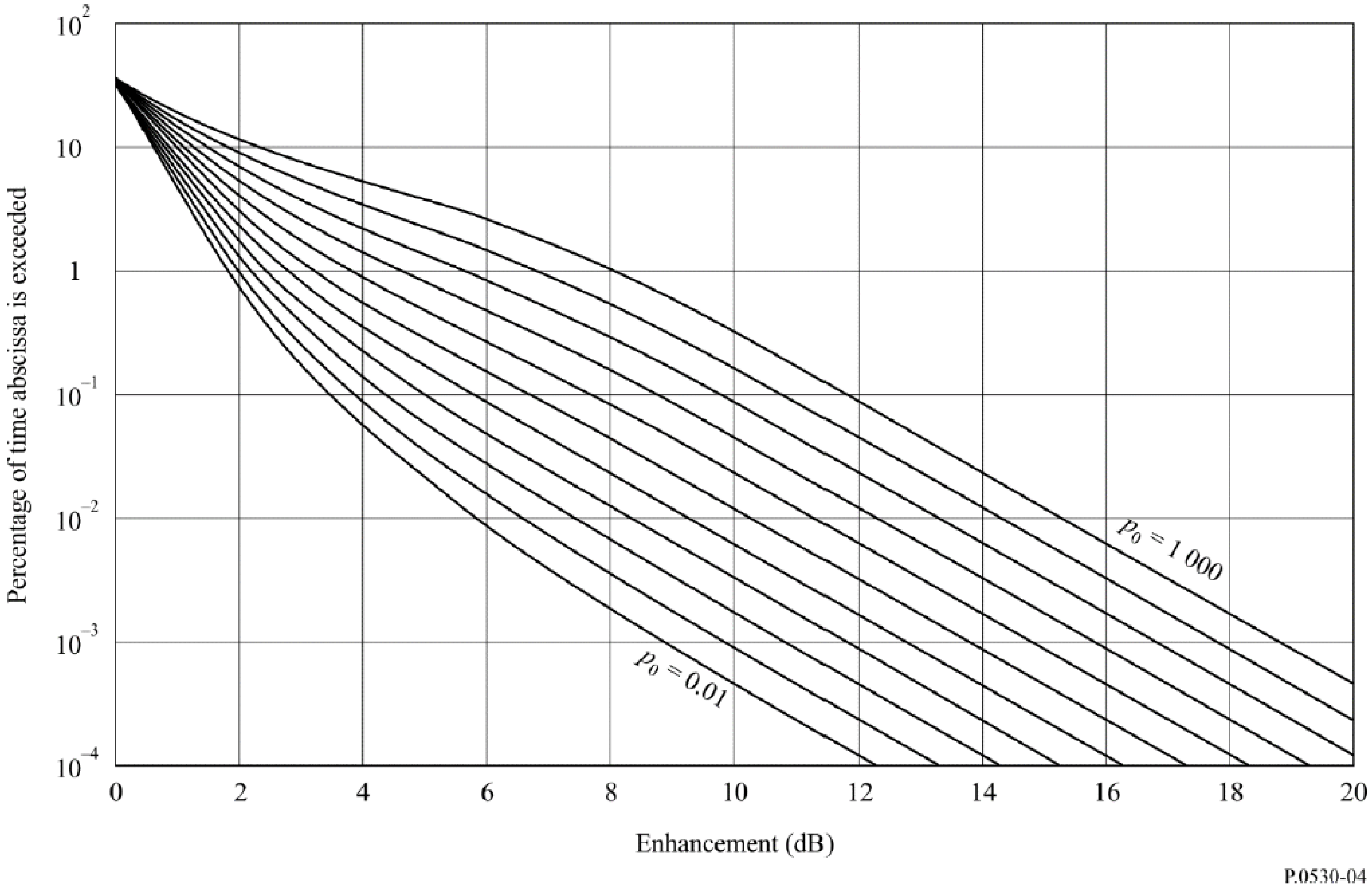
2.3.3 Prediction method for enhancement

...

FIGURE 4

Percentage of time, (100 – p_w), enhancement, E, exceeded in the average worst month, with p_0 (in equation (11)) ranging from 0.01 to 1 000



2.3.4 Conversion from average worst month to average annual distributions

. . .

2.3.5 Conversion from average worst month to shorter worst periods of time

. . .

2.3.6 Prediction of non-selective outage (see Note 1)

In the design of a digital link, calculate the probability of outage P_{ns} due to the non-selective component of the fading (see § 7) from:

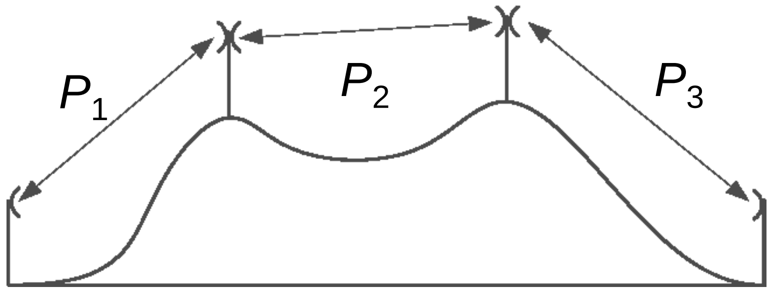
$$P_{ns} = p_w / 100 \tag{29}$$

where p_w (%) is the percentage of time that the flat fade margin $A = F$ (dB) corresponding to the specified bit error ratio (BER) is exceeded in the average worst month (obtained from § 2.3.1 or § 2.3.2, as appropriate). The flat fade margin, F, is obtained from the link calculation and the information supplied with the particular equipment, also taking into account possible reductions due to interference in the actual link design.

NOTE 1 – For convenience, the outage is here defined as the probability that the BER is larger than a given threshold, whatever the threshold (see § 7 for further information).

2.3.7 Occurrence of simultaneous fading on multi-hop links

. . .



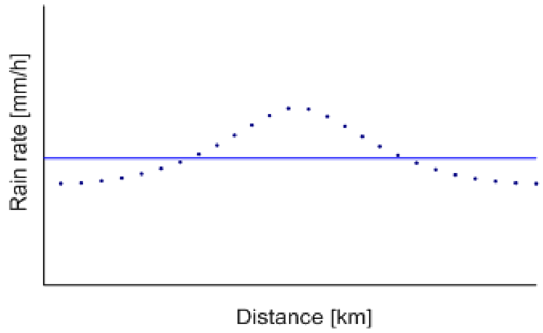
$$P_T = \sum_{i=1}^{n} P_i - \sum_{i=1}^{n-1} (P_i P_{i+1})^C \tag{30a}$$

$$C = 0.5 + 0.0052A + 0.0025(d_A + d_B) \tag{30b}$$

2.4 Attenuation due to hydrometeors

Attenuation can also occur as a result of absorption and scattering by such hydrometeors as rain, snow, hail and fog. Although rain attenuation can be ignored at frequencies below about 5 GHz, it must be included in design calculations at higher frequencies, where its importance increases rapidly. A technique for estimating long-term statistics of rain attenuation is given in § 2.4.1. On paths at high latitudes or high altitude paths at lower latitudes, wet snow can cause significant attenuation over an even larger range of frequencies. More detailed information on attenuation due to hydrometeors other than rain is given in Recommendation ITU-R P.840.

At frequencies where both rain attenuation and multipath fading must be taken into account, the exceedance percentages for a given fade depth corresponding to each of these mechanisms can be added.



2.4.1 Long-term statistics of rain attenuation

The following simple technique may be used for estimating the long-term statistics of rain attenuation:

Step 1: Obtain the rain rate $R_{0.01}$ exceeded for 0.01% of the time (with an integration time of 1 min). If this information is not available from local sources of long-term measurements, an estimate can be obtained from the information given in Recommendation ITU-R P.837.

26.2 mm/h

Step 2: Compute the specific attenuation, γ_R (dB/km) for the frequency, polarization and rain rate of interest using Recommendation ITU-R P.838.

0.14 dB/km

Step 3: Compute the effective path length, d_{eff}, of the link by multiplying the actual path length d by a distance factor r. An estimate of this factor is given by:

$$r = \frac{1}{0.477 d^{0.633} R_{0.01}^{0.073 \cdot \alpha} f^{0.123} - 10.579(1 - \exp(-0.024 d))} \tag{32}$$

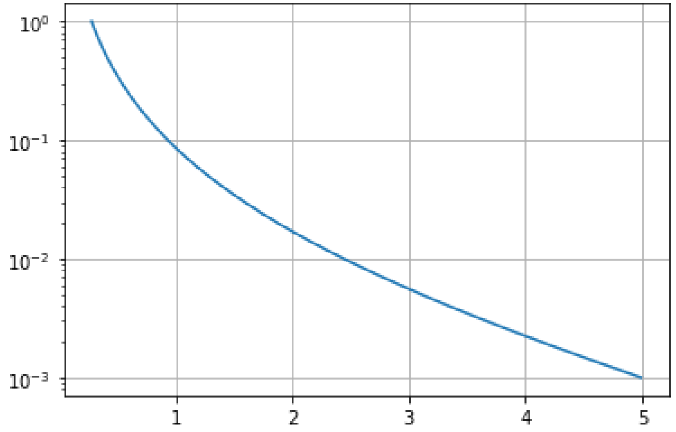
0,37

where f (GHz) is the frequency and α is the exponent in the specific attenuation model from Step 2.

Step 4: An estimate of the path attenuation exceeded for 0.01% of the time is given by:

$$A_{0.01} = \gamma_R \, d_{eff} = \gamma_R \, dr \qquad \text{dB} \qquad (33)$$

0.14 × 16.9 = 2.4 dB



Step 5: The attenuation exceeded for other percentages of time p in the range 0.001% to 1% may be deduced from the following power law:

$$\frac{A_p}{A_{0.01}} = C_1 \, p^{-(C_2 + C_3 \log_{10} p)} \qquad (34)$$

with:

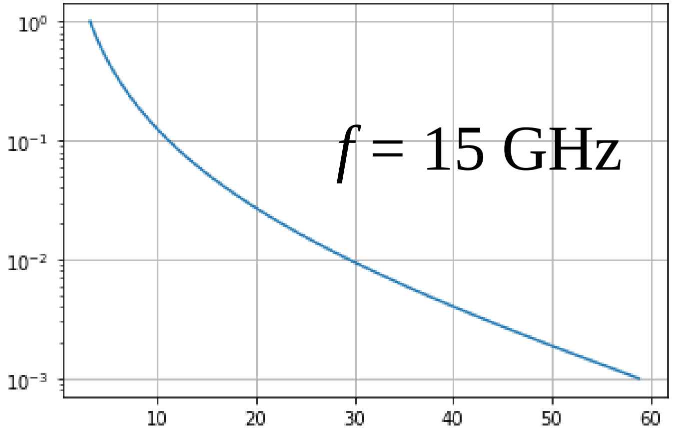
$$C_1 = \left(0.07^{C_0}\right)\left[0.12^{(1-C_0)}\right] \qquad (35a)$$

$$C_2 = 0.855 C_0 + 0.546(1 - C_0) \qquad (35b)$$

$$C_3 = 0.139 C_0 + 0.043(1 - C_0) \qquad (35c)$$

where:

$$C_0 = \begin{cases} 0.12 + 0.4\left[\log_{10}(f/10)^{0.8}\right] & f \geq 10\ GHz \\ 0.12 & f < 10\ GHz \end{cases} \qquad (36)$$



2.4.2 Combined method for rain and wet snow

…

…

…

$$P_{rain} = p/100$$

2.4.6 Rain attenuation in multiple hop networks

2.4.6.2 Correlated fading on tandem hops

If the occurrence of rainfall were statistically independent of location, then the overall probability of fading for a linear series of links in tandem would be given to a good approximation by:

$$P_T = \sum_{i=1}^{n} P_i \tag{80}$$

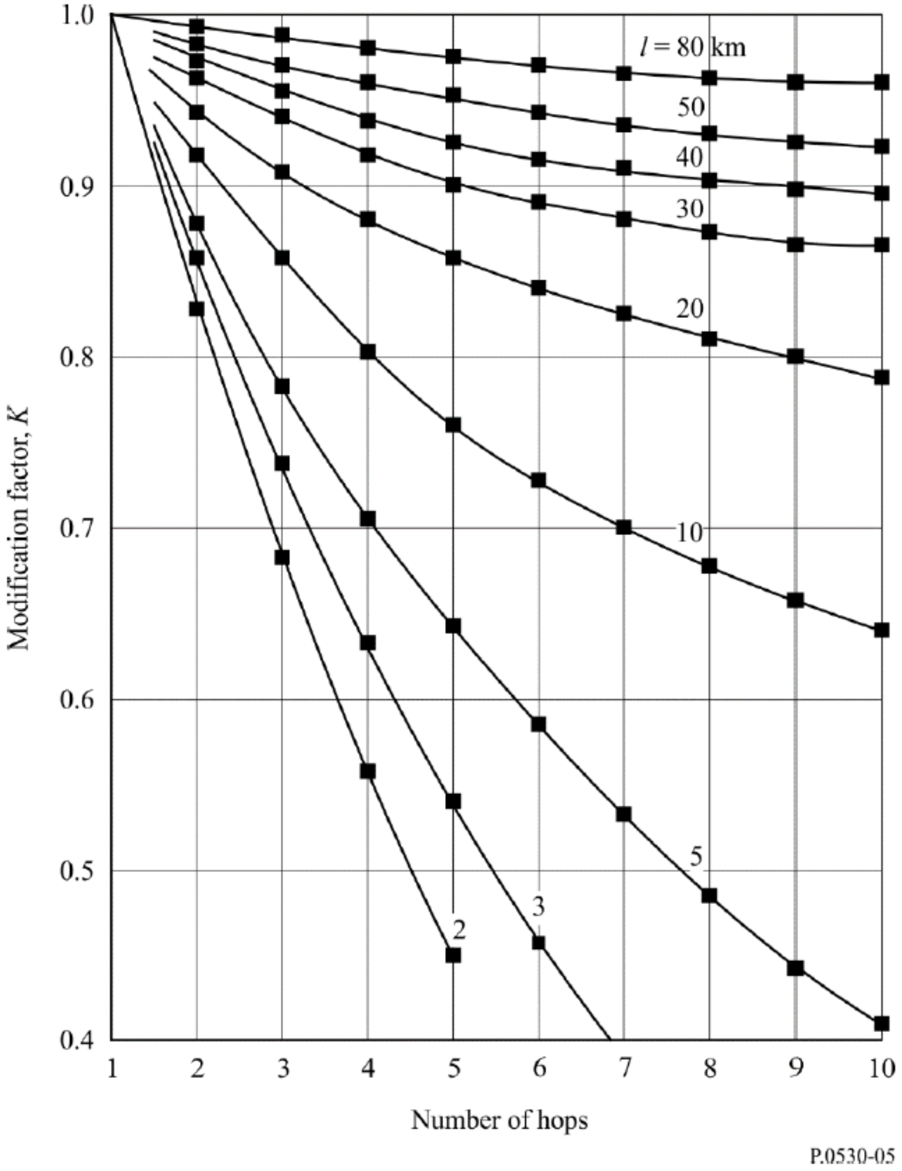
where P_i is the probability of fading for the i-th of the total n links.

On the other hand, if precipitation events are correlated over a finite area, then the attenuation on two or more links of a multi-hop relay system will also be correlated, in which case the combined fading probability may be written as:

$$P_T = K \sum_{i=1}^{n} P_i \tag{81}$$

where K is a modification factor that includes the overall effect of rainfall correlation.

Modification factor for joint rain attenuation on a series of tandem hops of equal length, *l*, for an exceedance probability of 0.03% for each link



4 Reduction of cross-polar discrimination (XPD)

The cross-polar discrimination (XPD) can deteriorate sufficiently to cause co-channel interference and, to a lesser extent, adjacent channel interference. The reduction in XPD that occurs during both clear-air and precipitation conditions must be taken into account.

4.1 Prediction of XPD outage due to clear-air effects

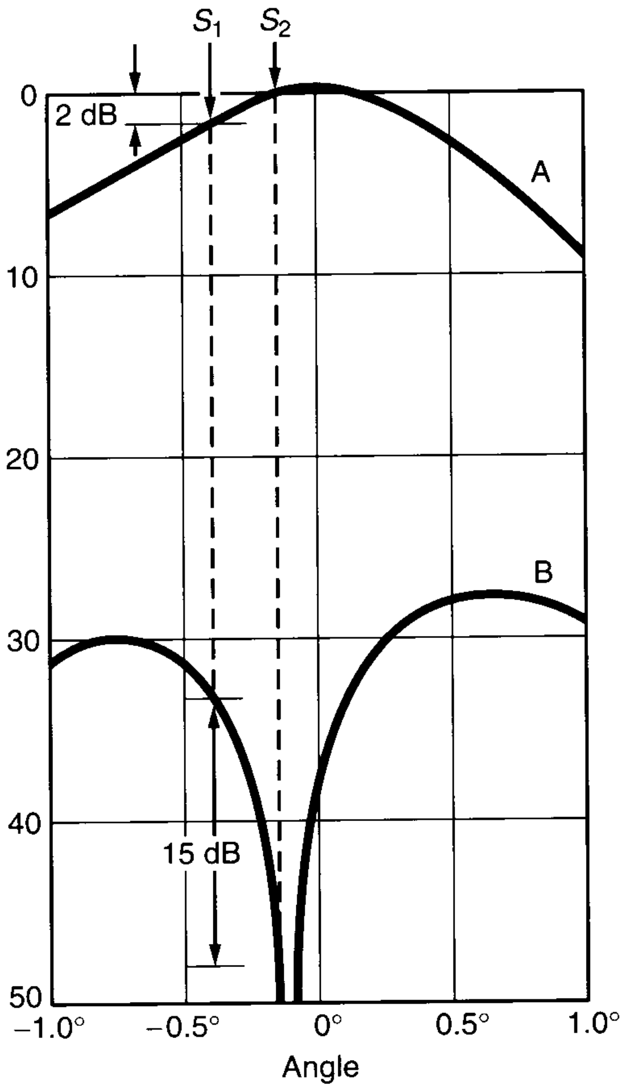
…

P_{XP}

4.2 Prediction of XPD outage due to precipitation effects

…

P_{XPR}

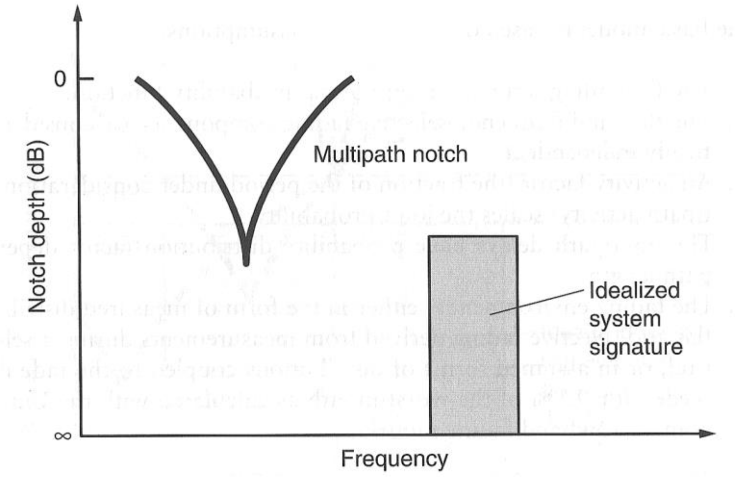


XPD Outage - Multipath

5 Distortion due to propagation effects

The primary cause of distortion on line-of-sight links in the UHF and SHF bands is the frequency dependence of amplitude and group delay during clear-air multipath conditions. In analogue systems, an increase in fade margin will improve the performance since the impact of thermal noise is reduced. In digital systems, however, the use of a larger fade margin will not help if it is the frequency selective fading that causes the performance reduction.

. . .



$$P_s = P_a \, P_b$$

P_s – selective outage probability

P_a – probability of critical deep fade occurrence

P_b – probability the fading within the system signature frequency interval

6 Techniques for alleviating the effects of multipath propagation

The effects of slow relatively non-frequency selective fading (i.e. flat fading) due to beam spreading, and faster frequency-selective fading due to multipath propagation must both be taken into account in link design. There are a number of techniques available for alleviating these effects, most of which alleviate both at the same time. The same techniques often alleviate the reductions in cross-polarization discrimination also. They can be categorized as techniques that do not require some kind of diversity reception or transmission, and techniques that do require diversity.

Since it is desirable for economic reasons to avoid diversity whenever possible, strategies and techniques that do not require diversity are considered first in § 6.1. These strategies and techniques are also relevant for diversity systems, however, and should be employed when convenient even though they may be less necessary. Diversity techniques are discussed in § 6.2.

6.1 Techniques without diversity

In order to reduce the effects of multipath fading without diversity there are several techniques that can be employed either if the link is between existing towers or between new towers to be built. It is useful to consider these techniques as accomplishing one or more of the following Strategies:

Strategy A: reducing the occurrence of significant flat fading due to atmospheric mechanisms (beam spreading, antenna decoupling, and atmospheric multipath; see § 2.3);

Strategy B: reducing the occurrence of significant surface reflections;

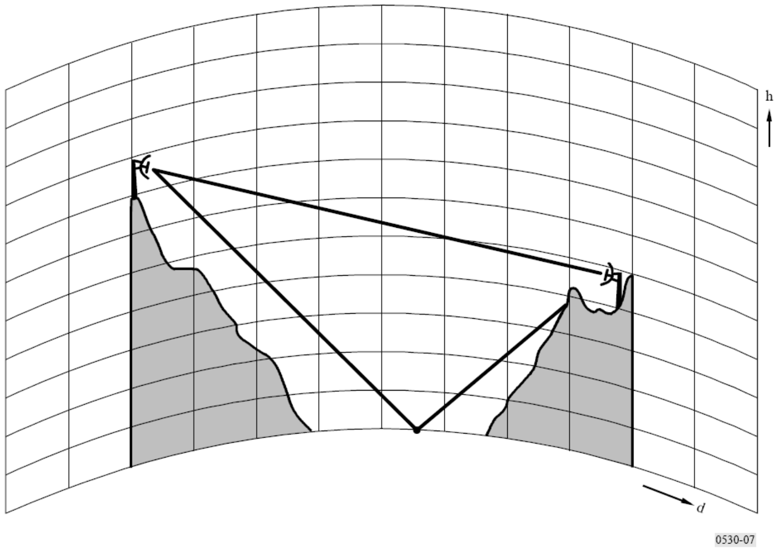
Strategy C: reducing the relative delay of the surface reflections with respect to the atmospheric wave.

Techniques without diversity

- Strategies
  - A - reducing the occurrence of significant flat fading due to atmospheric mechanisms
  - B - reducing the occurrence of significant surface reflections
  - C - reducing the relative delay of the surface reflections with respect to the atmospheric wave
- Methods
  - Increase of path inclination; A (B)
  - Reduction of effect of surface reflections; B
    - Shielding of the reflection point
    - Moving of reflection point to poorer reflecting surface (calculation/measurement of effective surface reflection coefficient)
    - Optimum choice of antenna heights
    - Choice of vertical polarization
    - Use of antenna discrimination
  - Reduction of path clearance; A, B, C

FIGURE 7

Example of shielding of antenna from specular reflection



$$\rho_{eff} = \rho D R_s R_r$$

6.2 Diversity techniques

Diversity techniques include space, angle and frequency diversity. Normally the use of frequency diversity should be avoided in favour of space diversity, angle diversity, or a combination of the two. Not only is the frequency spectrum used more efficiently in this manner, but also these techniques are generally superior. Space diversity, in particular, helps to combat flat fading (such as caused by beam spreading loss, not by atmospheric multipath with short relative delay) as well as frequency selective fading, whereas frequency diversity only helps to combat frequency selective fading (such as caused by surface multipath and/or atmospheric multipath). Frequency diversity should be avoided whenever possible so as to conserve spectrum. Whenever space diversity is used, angle diversity should also be employed by tilting the antennas at different upward angles. Angle diversity can be used in situations in which adequate space diversity is not possible or to reduce tower heights.

…

The diversity improvement factor, I, for fade depth, A, is defined by:

$$I = p(A) \,/\, p_d(A) \tag{150}$$

where $p_d(A)$ is the percentage of time in the combined diversity signal branch with fade depth larger than A and $p(A)$ is the percentage for the unprotected path. The diversity improvement factor for digital systems is defined by the ratio of the exceedance times for a given BER with and without diversity.

6.2.1 Antenna spacing in space diversity systems

6.2.2 Angular spacing in angle-diversity and combined space/angle-diversity systems

6.2.3 Frequency separation in frequency diversity systems

… prediction of outage with diversity…

7 Prediction of total outage

Calculate the total outage probability due to clear-air effects from:

$$P_t = \begin{cases} P_{ns} + P_s + P_{XP} & \\ P_d + \dfrac{P_{XP}}{I} & \text{if diversity is used} \end{cases} \tag{177}$$

obtained by methods given in §§ 2.3.6, 4.1, 5.1, 6.2.4 and 6.2.5.

The total outage probability due to rain is calculated from taking the larger of P_{rain} and P_{XPR} obtained by methods given in §§ 2.4.7 and 4.2.2.

The outage prediction methods given for digital radio systems have been developed from a definition of outage as BER above a given value (e.g. 1×10^{-3}) for meeting requirements set out in Recommendation ITU-T G.821. The outage is apportioned to error performance and availability (see Recommendations ITU-R F.594, ITU-R F.634, ITU-R F.695, ITU-R F.696, ITU-R F.697, ITU-R F.1092, ITU-R F.1189 and ITU-R F.557). The outage due to clear-air effects is apportioned mostly to performance and the outage due to precipitation, predominantly to availability. However, it is likely that there will be contributions to availability from clear-air effects and contributions to performance from precipitation.