

RECOMMENDATION ITU-R P.682-1*

**PROPAGATION DATA REQUIRED FOR THE DESIGN OF EARTH-SPACE
AERONAUTICAL MOBILE TELECOMMUNICATION SYSTEMS**

(Question ITU-R 207/3)

(1990-1992)

The ITU Radiocommunication Assembly,

considering

- a) that for the proper planning of Earth-space aeronautical mobile systems it is necessary to have appropriate propagation data and prediction methods;
- b) that the methods of Recommendation ITU-R P.618 are recommended for the planning of Earth-space telecommunication systems;
- c) that further development of prediction methods for specific application to aeronautical mobile-satellite systems is required to give adequate accuracy for all operational conditions;
- d) that, however, methods are available which yield sufficient accuracy for many applications,

recommends

that the methods contained in Annex 1 be adopted for current use in the planning of Earth-space aeronautical mobile telecommunication systems, in addition to the methods recommended in Recommendation ITU-R P.618.

ANNEX 1

1. Introduction

Propagation effects in the aeronautical mobile-satellite service differ from those in the fixed-satellite service and other mobile-satellite services because:

- small antennas are used on aircraft, and the aircraft body may affect the performance of the antenna;
- high aircraft speeds cause large Doppler spreads;
- aircraft terminals must accommodate a large dynamic range in transmission and reception;
- aircraft safety considerations require a high integrity of communications, making even short-term propagation impairments very important, and communications reliability must be maintained in spite of banking manoeuvres and three-dimensional operations.

This Annex discusses data and models specifically required to characterize the path impairments, which include:

- tropospheric effects, including gaseous attenuation, cloud and rain attenuation, fog attenuation, refraction and scintillation;
- ionospheric effects such as scintillation;
- surface reflection (multipath) effects;
- environmental effects (aircraft motion, sea state, land surface type).

* Radiocommunication Study Group 3 made editorial amendments to this Recommendation in 2000 in accordance with Resolution ITU-R P.44.

Aeronautical mobile-satellite systems may operate on a worldwide basis, including propagation paths at low elevation angles. Several measurements of multipath parameters over land and sea have been conducted. In some cases, laboratory simulations are used to compare measured data and verify model parameters. The received signal is considered in terms of its possible components: a direct wave subject to atmospheric effects, and a reflected wave, which generally contains mostly a diffuse component.

There is current interest in using frequencies near 1.5 GHz for aeronautical mobile-satellite systems. As most experiments have been conducted in this band, data in this Recommendation are mainly applicable to these frequencies. As aeronautical systems mature, it is anticipated that other frequencies may be used.

2. Tropospheric effects

For the aeronautical services, the altitude of the mobile antenna is an important parameter. Estimates of tropospheric attenuation may be made with the methods in Recommendation ITU-R P.618.

The received signal may be affected both by large-scale refraction and by scintillations induced by atmospheric turbulence. These effects will diminish for aircraft at high altitudes.

3. Ionospheric effects

Ionospheric effects on slant paths are discussed in Recommendation ITU-R P.531. These phenomena are important for many paths at frequencies below about 10 GHz, particularly within $\pm 15^\circ$ of the geomagnetic equator, and to a lesser extent, within the auroral zones and polar caps. Ionospheric effects peak near the solar sunspot maximum.

Impairments caused by the ionosphere will not diminish for the typical altitudes used by aircraft. A summary description of ionospheric effects of particular interest to mobile-satellite systems is available in Recommendation ITU-R P.680. For most communication signals, the most severe impairment will probably be ionospheric scintillation. Table 1 of Recommendation ITU-R P.680 provides estimates of maximum expected ionospheric effects at frequencies up to 10 GHz for paths at a 30° elevation angle.

4. Fading due to surface reflection and scattering

4.1 General

Multipath fading due to surface reflections for aeronautical mobile-satellite systems differs from fading for other mobile-satellite systems because the speeds and altitudes of aircraft are much greater than those of other mobile platforms. Characteristics of fading for aeronautical systems can be analysed with procedures similar to those for maritime systems described in Recommendation ITU-R P.680, taking careful account of earth sphericity, which becomes significant with increasing antenna altitude above the reflecting surface.

4.2 Fading due to sea-surface reflections

4.2.1 Dependence on antenna height and antenna gain

The following simple method, based on a theoretical model, provides approximate estimates of multipath power or fading depth suitable for engineering applications.

The procedure is as follows:

Applicable range:

Frequency: 1-2 GHz
 Elevation angle: $\theta_i \geq 3^\circ$ and $G(1.5\theta_i) \geq -10$ dB

where $G(\theta)$ is the main-lobe antenna pattern given by:

$$G(\theta) = -4 \times 10^{-4} (10^{G_m/10} - 1) \theta^2 \quad \text{dB} \quad (1)$$

where:

G_m : value of the maximum antenna gain (dB)
 θ : angle measured from boresight (degrees).
 Polarization: circular and horizontal polarizations; vertical polarization for $\theta_i \geq 8^\circ$
 Sea condition: wave height of 1-3 m (incoherent component fully developed).

Step 1: Calculate the grazing angles of the specular reflection point, θ_{sp} , and the horizon, θ_{hr} , by:

$$\theta_{sp} = 2 \gamma_{sp} + \theta_i \quad \text{degrees} \quad (2a)$$

$$\theta_{hr} = \cos^{-1} [R_e / (R_e + H_a)] \quad \text{degrees} \quad (2b)$$

where:

$$\gamma_{sp} = 7.2 \times 10^{-3} H_a / \tan \theta_i$$

R_e : radius of the Earth = 6 371 km

H_a : antenna height (km)

Step 2: Find the relative antenna gain G in the direction midway between the specular point and the horizon. The relative antenna gain is approximated by equation (1) where $\theta = \theta_i + (\theta_{sp} + \theta_{hr})/2$ (degrees).

Step 3: Calculate the Fresnel reflection coefficient of the sea:

$$R_H = \frac{\sin \theta_i - \sqrt{\eta - \cos^2 \theta_i}}{\sin \theta_i + \sqrt{\eta - \cos^2 \theta_i}} \quad \text{(horizontal polarization)} \quad (3a)$$

$$R_V = \frac{\sin \theta_i - \sqrt{(\eta - \cos^2 \theta_i) / \eta^2}}{\sin \theta_i - \sqrt{(\eta - \cos^2 \theta_i) / \eta^2}} \quad \text{(vertical polarization)} \quad (3b)$$

$$R_C = \frac{R_H + R_V}{2} \quad \text{(circular polarization)} \quad (3c)$$

$$\eta = \epsilon_r(f) - j 60 \lambda \sigma(f)$$

where:

$\epsilon_r(f)$: relative permittivity of the surface at frequency f (from Recommendation ITU-R P.527)

$\sigma(f)$: conductivity (S/m) of the surface at frequency f (from Recommendation ITU-R P.527)

λ : free space wavelength (m).

Step 4: Calculate the correction factor C_θ (dB):

$$C_\theta = \begin{cases} 0 & \text{for } \theta_{sp} \geq 7^\circ \\ (\theta_{sp} - 7) / 2 & \text{for } \theta_{sp} < 7^\circ \end{cases} \quad (4)$$

Step 5: Calculate the divergence factor D (dB) due to the Earth's curvature:

$$D = -10 \log \left[1 + \frac{2 \sin \gamma_{sp}}{\cos \theta_{sp} \sin (\gamma_{sp} + \theta_i)} \right] \quad (5)$$

Step 6: The mean incoherent power of sea reflected waves, relative to the direct wave, P_r , is given by:

$$P_r = G + R + C_\theta + D \quad \text{dB} \quad (6)$$

where:

$$R = 20 \log |R_i|$$

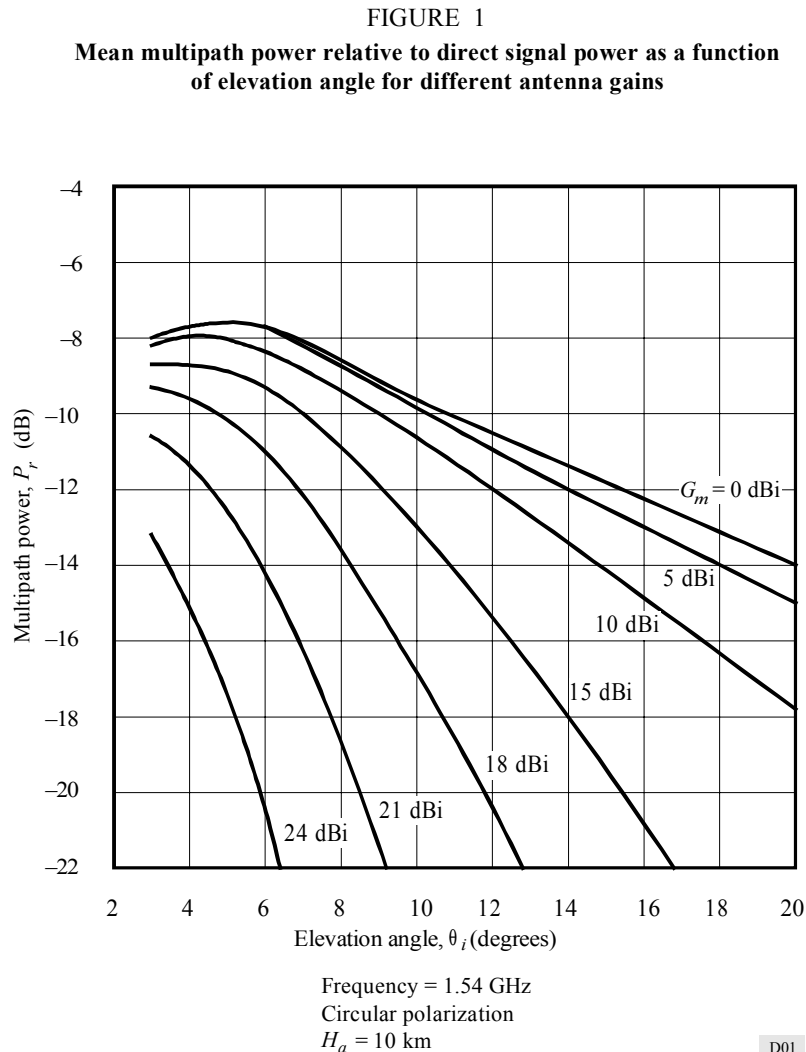
with $R_i = R_H, R_V$ or R_C from equations (3).

Step 7: Assuming the Nakagami-Rice distribution, fading depth is estimated from:

$$A + 10 \log \left(1 + 10^{P_r/10} \right) \quad (7)$$

where A is the amplitude (dB) read from the ordinate of Fig. 1 of Recommendation ITU-R P.680.

Figure 1 below shows the mean multipath power of the incoherent component obtained by the above method as a function of the elevation angle for different gains. By comparing with the case of maritime mobile-satellite systems (Fig. 2 of Recommendation ITU-R P.680), it can be seen that the reflected wave power P_r for aeronautical mobile-satellite systems is reduced by 1 to 3 dB at low elevation angles.

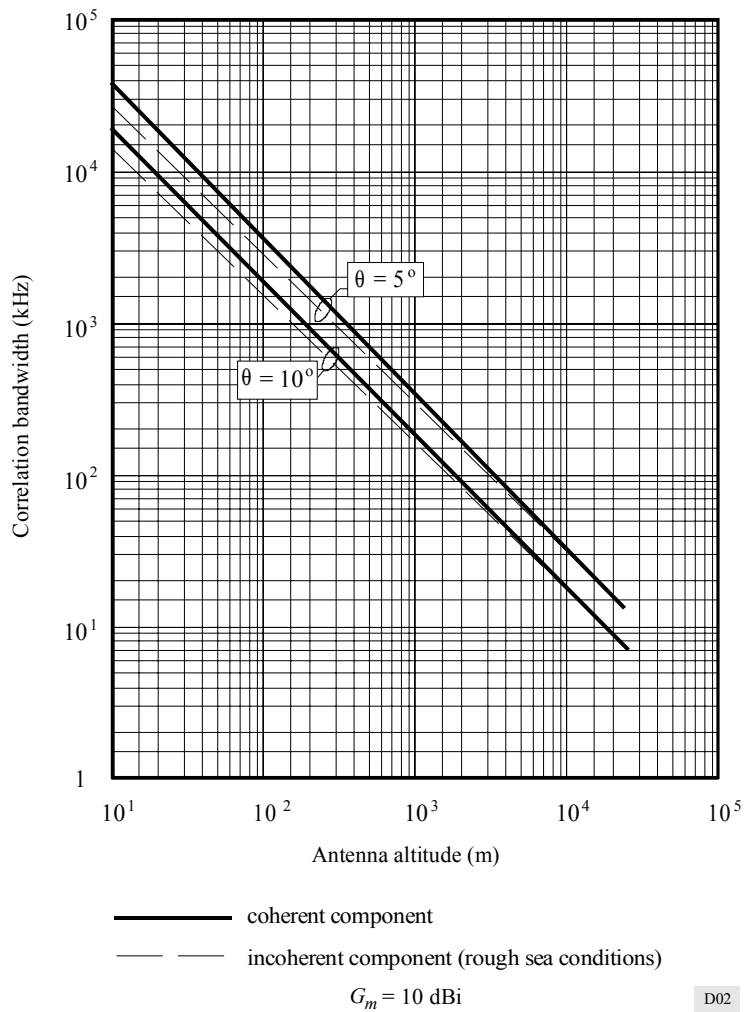


Note 1 – Analytical as well as experimental studies have shown that for circularly polarized waveforms at or near 1.5 GHz and an antenna gain of 7 dB, multipath fade depth for rough sea conditions is about 8 to 11 dB for low and moderate aircraft heights and about 7 to 9 dB for high altitudes (above 2 km). Multipath fade depth is about 2 dB lower for a 15 dB antenna gain.

4.2.2 Delay time and correlation bandwidth

The received signal consists of the direct and the reflected waveforms. Because the reflected component experiences a larger propagation delay than the direct component, the composite received signal may be subject to frequency-selective fading. Signal correlation decreases with increasing frequency separation. The dependence of correlation on the antenna gain is small for gains below 15 dB. Figure 2 shows the relationship between antenna height and the correlation bandwidth, defined here as the frequency separation for which the correlation coefficient between two radio waves equals 0.37 (1/e). The correlation bandwidth decreases as the antenna altitude increases, becoming about 10 to 20 kHz (delay time of 6 to 12 μs) for an antenna at an altitude of 10 km. Thus, multipath fading for aeronautical systems may have frequency-selective characteristics.

FIGURE 2
Correlation bandwidth vs antenna altitude
for antenna gain of 10 dBi



4.3 Measurements of sea-reflection multipath effects

Extensive experiments have been conducted in the 1.5 to 1.6 GHz band. Results of these measurements are summarized in this section for application to systems design.

Table 1 summarizes the oceanic multipath parameters observed in measurements, augmented with results from an analytical model. The delay spreads in the table are the widths of the power-delay profile of the diffusely-scattered signal arriving at the receiver. The correlation bandwidth given in Table 1 is the 3 dB bandwidth of the frequency autocorrelation function (Fourier transform of the delay spectrum). Doppler spread is determined from the width of the Doppler power spectral density. The decorrelation time is the 3 dB width of the time autocorrelation function (inverse Fourier transform of the Doppler spectrum).

TABLE 1

Multipath parameters from ocean measurements

Parameter	Measured range	Typical value at specified elevation angle		
		8°	15°	30°
Normalized multipath power (dB)				
Horizontal polarization	−5.5 to −0.5	−2.5	−1	−1
Vertical polarization	−15 to −2.5	−14	−9	−3.5
Delay spread ⁽¹⁾ (μs)				
3 dB value	0.25-1.8	0.6	0.8	0.8
10 dB value	2.2 -5.6	2.8	3.2	3.2
Correlation bandwidth ⁽²⁾				
3 dB value (kHz)	70-380	160	200	200
Doppler spread ⁽¹⁾ (Hz)				
In-plane geometry				
3 dB value	4-190	5	70	140
10 dB value	13-350	44 40 ⁽³⁾	180	350
Cross-plane geometry				
3 dB value	79-240	79	110	190
10 dB value	180-560	180 80 ⁽³⁾	280	470
Decorrelation time ⁽²⁾ (ms)				
3 dB value	1.3-10	7.5	3.2	2.2

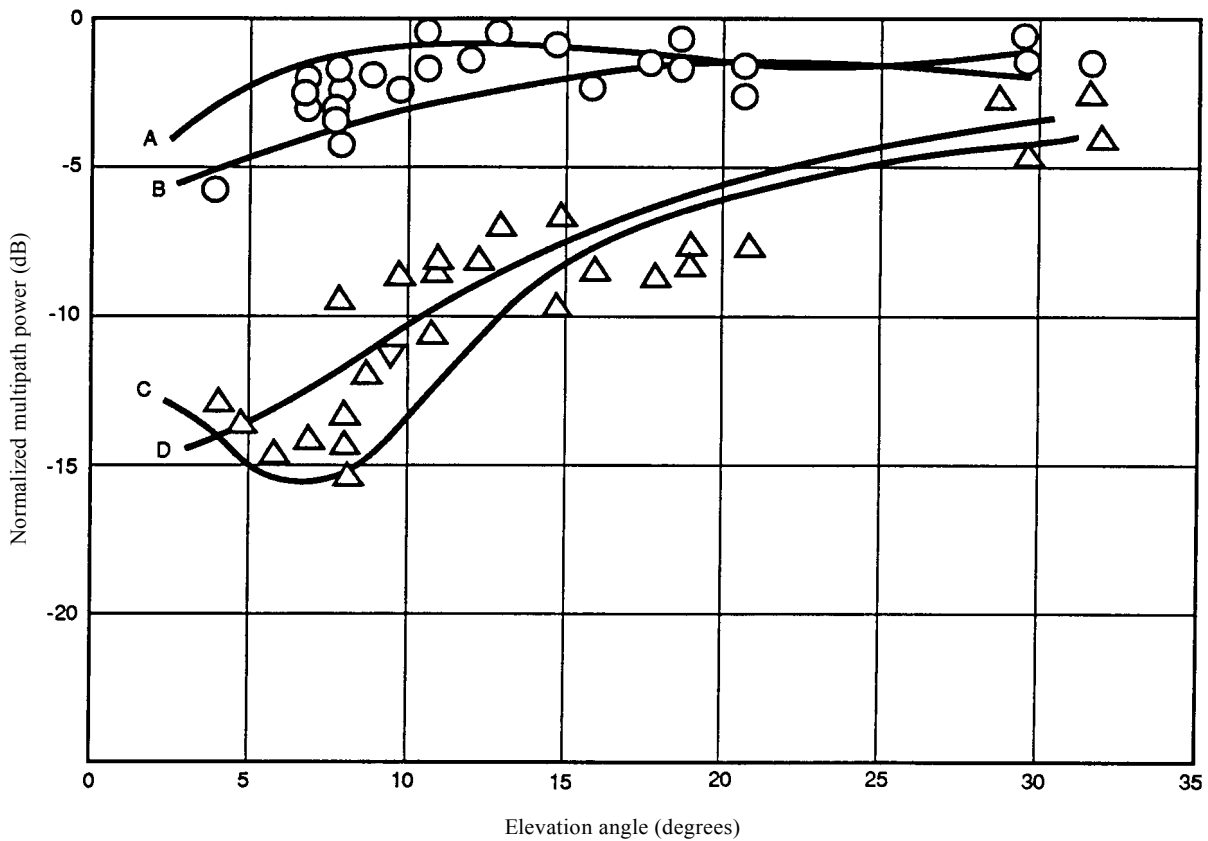
(1) Two-sided.

(2) One-sided.

(3) Data from multipath model for aircraft altitude of 10 km and aircraft speed of 1 000 km/h.

Normalized multipath power for horizontal and vertical antenna polarizations for calm and rough sea conditions are plotted versus elevation angle in Fig. 3, along with predictions derived from a physical optics model. Sea condition has a minor effect for elevation angles above about 10°. The agreement between measured coefficients and those predicted for a smooth flat Earth as modified by the spherical-Earth divergence factor increases as sea conditions become calm.

FIGURE 3
Oceanic normalized multipath power vs elevation angle at 1.6 GHz



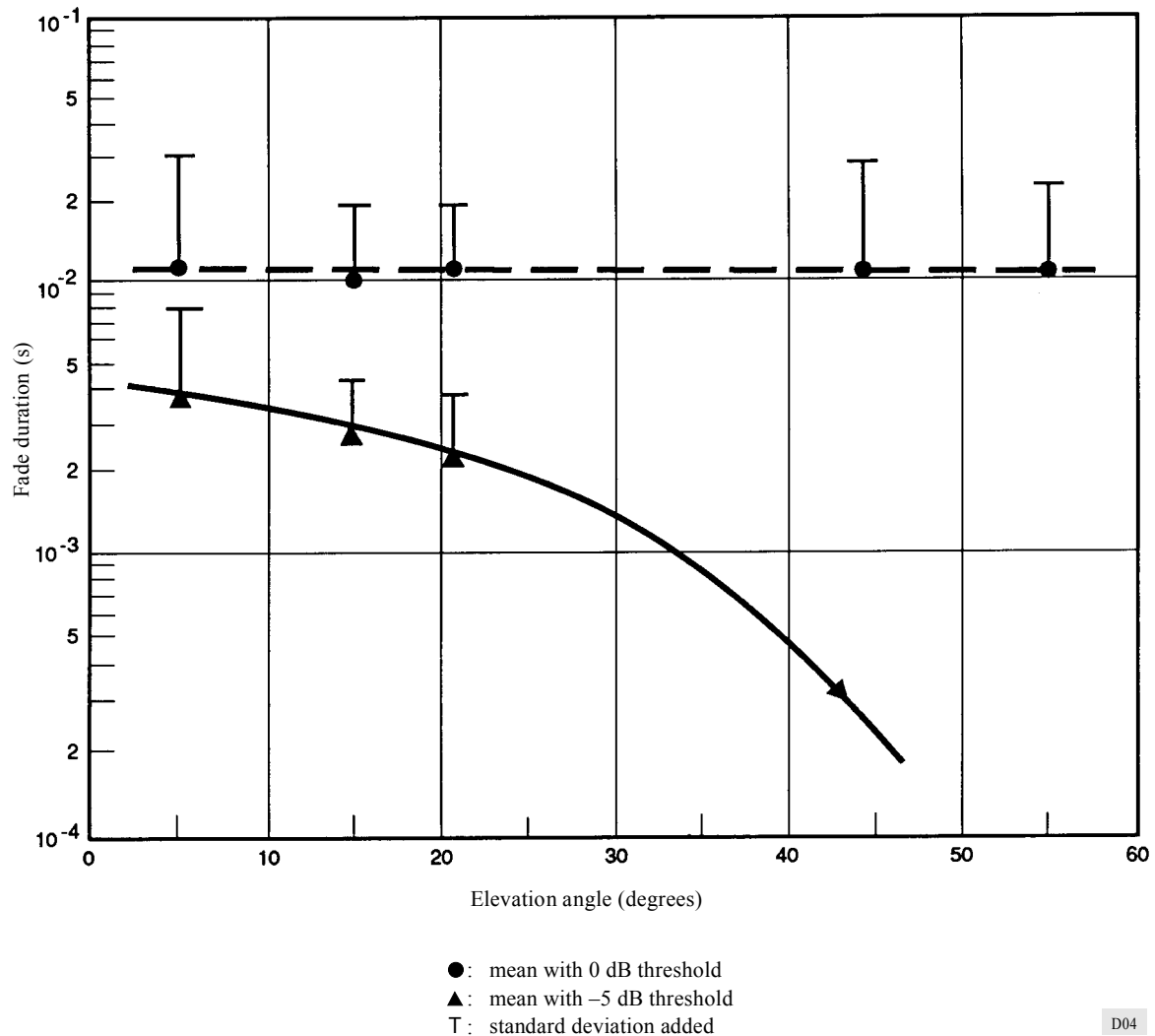
- O : horizontal polarization measurements
- Δ : vertical polarization measurements
- Curves A : horizontal polarization prediction, calm sea
- B : horizontal polarization prediction, rough sea
- C : vertical polarization prediction, calm sea
- D : vertical polarization prediction, rough sea

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Multipath data were collected in a series of aeronautical mobile-satellite measurements conducted over the Atlantic Ocean and parts of Europe. Figure 4 shows the measured mean and standard deviations of 1.6 GHz fade durations as a function of elevation angle for these flights. (A crossed-dipole antenna with a gain of 3.5 dBi was used to collect these data. The aircraft flew at a nominal altitude of 10 km and with a nominal ground speed of 700 km/h.)

FIGURE 4

Fade duration vs elevation angle for circular polarization
at 1.6 GHz (antenna gain = 3.5 dBi); data collected over
Atlantic Ocean and W. Europe



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4.4 Measurements of land-reflection multipath effects

Table 2 supplies multipath parameters measured during flights over land; parameter definitions are the same as for Table 1. Land multipath signals are highly variable. No consistent dependence on elevation angle has been established, perhaps because ground terrain is highly variable (data were collected over wet and dry soil, marshes, dry and wet snow, ice, lakes, etc.).

Note 1 – Irreducible error rate; multipath fading in mobile channels gives rise to an irreducible error rate at which increases in the direct signal power do not reduce the corresponding error rate. Simulations indicate that the irreducible error rate is higher for an aeronautical mobile-satellite channel than for a land mobile-satellite channel.

TABLE 2

Multipath parameters from land measurements

Parameter	Measured range	Typical value
Normalized multipath power (dB)		
Horizontal polarization	-18 to 2	- 9
Vertical polarization	-21 to -3	-13
Delay spread ⁽¹⁾ (μs)		
3 dB value	0.1-1.2	0.3
10 dB value	0.2-3	1.2
Correlation bandwidth ⁽²⁾ (kHz)		
3 dB value	150-3 000	600
Doppler spread ⁽¹⁾ (Hz)		
3 dB value	20-140	60
10 dB value	40-500	200
Decorrelation time ⁽²⁾ (ms)		
3 dB value	1-10	4

(1) Two-sided.

(2) One-sided.