

RECOMMENDATION ITU-R P.679-3

**Propagation data required for the design of
broadcasting-satellite systems**

(Question ITU-R 206/3)

(1990-1992-1999-2001)

The ITU Radiocommunication Assembly,

considering

- a) that for the proper planning of broadcasting-satellite 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 broadcasting-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

1 that the propagation data contained in Annex 1 be adopted for use in the planning of broadcasting-satellite systems, in addition to the methods recommended in Recommendation ITU-R P.618.

ANNEX 1

1 Introduction

Broadcasting by satellite leads to propagation considerations that are not entirely comparable with those occurring in the fixed-satellite service. Attenuation data for the space-to-Earth direction are needed in the form of statistical averages and/or contour maps of attenuation and depolarization for large areas. Specific coordination problems may arise at the margin of the service area between satellite broadcasting systems and terrestrial or other space services. General methods for prediction of Earth-space path propagation effects are presented in Recommendation ITU-R P.618. Additional information specific to satellite broadcasting system planning is treated in this Annex. It should be noted that feeder links are considered to be part of fixed-satellite services, not the broadcasting services.

In the case of space-to-Earth paths for broadcasting systems, several propagation effects may require consideration.

Among these are:

- tropospheric effects, including gaseous absorption, and attenuation and depolarization by rain and other hydrometeors;
- ionospheric effects such as scintillation and Faraday rotation (see Recommendation ITU-R P.531);
- local environmental effects, including attenuation by buildings and vegetation.

This Annex discusses these effects and refers to other Recommendations for additional information. More data are needed to characterize propagation impairments for satellite broadcasting systems.

2 Tropospheric effects

Signal impairments caused by the troposphere are negligible for frequencies below about 1 GHz and path elevation angles exceeding 10°.

As elevation decreases and/or frequency increases these impairments become more and more severe and fluctuations of signal amplitude and angle of arrival can be significant (see Recommendation ITU-R P.618). The latter effects are of particular importance for high latitude service areas. Sky-noise temperature increases caused by precipitation (see Recommendation ITU-R P.618) will further reduce C/N of the received signal. In addition, snow and ice accumulations on reflector and feed surfaces of the antenna can seriously degrade antenna pointing, gain and cross-polar characteristics for significant portions of a year.

2.1 Attenuation in the troposphere

Signal losses in the troposphere are caused by gaseous absorption and attenuation by rain and other hydrometeors. In addition, small-scale variations in the atmospheric refractive index cause signal scintillations that contribute both to signal fading and enhancements.

2.1.1 Attenuation by atmospheric gases

The recommended method for predicting gaseous attenuation on Earth-satellite paths is found in Recommendation ITU-R P.618. For most frequencies, gaseous attenuation is of minor importance in relation to rain attenuation. In the 22 GHz band allocated to the broadcasting-satellite service in some regions, however, water vapour absorption can be quite large. For example, at a location where the 22.75 GHz path attenuation exceeds 9.5 dB for 1% of the worst month, about 3 dB of the total is the result of gaseous attenuation.

2.1.2 Precipitation and cloud attenuation

The prediction procedure for precipitation and cloud attenuation is given in Recommendation ITU-R P.618, along with a simple method for the frequency scaling of measured attenuation statistics. Attenuation due to cloud will not be serious for frequencies below 30 GHz, and is

accounted for in the rain attenuation prediction method in any case. Fog and cloud attenuation may be estimated if the liquid-water content is known, using the method contained in Recommendation ITU-R P.840.

2.1.3 Rain attenuation for worst month

For satellite broadcast applications, the rain attenuation exceeded for 1% of the worst month is usually of greatest concern. The method for relating worst-month time percentages to annual time percentages for rain attenuation is provided in Recommendation ITU-R P.618. A full treatment of the worst month and its basis is found in Recommendation ITU-R P.581.

Available worst-month rain attenuation data are compiled in Table II-2 of the Radiocommunication Study Group 3 data banks (see Recommendation ITU-R P.311).

2.1.4 Diurnal variation of fading

The dependence of signal fading on the time of day is a significant consideration in the provision of broadcasting-satellite services. Fading data obtained in various regions of the world exhibit a common tendency for the larger fades to occur in the afternoon and early evening hours. In climates characterized by thunderstorms, an increased probability of occurrence of deep fading is associated with the time of maximum local thunderstorm activity. Tropical locations in particular can show a strong diurnal asymmetry.

Low-level fading, on the other hand, is more evenly distributed, both seasonally and diurnally.

2.1.5 Scintillation fading

Small-scale irregularities in the tropospheric refractive index can induce rapid fluctuations in signal amplitude. Signal scintillations are not generally significant contributors to system performance for frequencies below about 10 GHz and path elevation angles above 10°, but can be important at low elevation angles or higher frequencies, especially for small-margin links. The method recommended for the estimation of scintillation fading is obtained from Recommendation ITU-R P.618.

2.2 Depolarization

Hydrometeors, principally concentrations of rain drops and ice crystals, can cause statistically significant depolarization of signals at frequencies above about 2 GHz. The recommended procedure for the prediction of these effects is found in Recommendation ITU-R P.618.

3 Ionospheric effects

At frequencies below about 3 GHz, ionospheric effects are important on some paths and at some locations. For general engineering use, estimated maximum values of ionospheric effects (obtained from Recommendation ITU-R P.531) are summarized in Table 1 for various frequencies. The impairments of most concern are typically signal scintillation and (for linearly polarized waves only) Faraday rotation.

TABLE 1

Estimated* ionospheric effects for elevation angles of about 30° one-way traversal**
(derived from Recommendation ITU-R P.531)

Effect	Frequency dependence	0.5 GHz	1 GHz	3 GHz	10 GHz
Faraday rotation	$1/f^2$	1.2 rotation	108°	12°	1.1°
Propagation delay	$1/f^2$	1 μ s	0.25 μ s	0.028 μ s	0.0025 μ s
Refraction	$1/f^2$	< 2.4'	< 0.6'	< 4.2"	< 0.36"
Variation in the direction of arrival (r.m.s. value)	$1/f^2$	48"	12"	1.32"	0.12"
Absorption (auroral and/or polar cap)	$\approx 1/f^2$	0.2 dB	0.05 dB	6×10^{-3} dB	5×10^{-4} dB
Absorption (mid-latitude)	$1/f^2$	< 0.04 dB	< 0.01 dB	< 0.001 dB	< 1×10^{-4} dB
Dispersion	$1/f^3$	0.0032 ps/Hz	0.0004 ps/Hz	1.5×10^{-5} ps/Hz	4×10^{-7} ps/Hz
Scintillation ⁽¹⁾			> 20 dB peak-to-peak	≈ 10 dB peak-to-peak	≈ 4 dB peak-to-peak

* This estimate is based on a total electron content (TEC) of 10^{18} electrons/m², which is a high value of TEC encountered at low latitudes in daytime with high solar activity

** Ionospheric effects above 10 GHz are negligible.

(1) Values observed near the geomagnetic equator during the early night-time hours (local time) at equinox under conditions of high sunspot number.

4 Effects of local environment

In specific receiving locations, effects of local structures and vegetation may be important. Recent measurement results at 5 GHz show a strong dependence of the building entry loss on the elevation and azimuth angles. These results augment results obtained from measurements in the bands below 3 GHz. Unfortunately, data for application to satellite broadcasting are insufficient to characterize fully these effects.

4.1 Building entry loss

Representative UHF satellite signal attenuation observed within rooms located near an exterior wall in timber-framed private homes is summarized in Table 2. For interior rooms, 0.6 dB must be added to the tabulated values. For timber-framed buildings the attenuation shows little variation with weather or path elevation angle but, as the Table illustrates, there is a systematic variation with frequency, polarization, construction materials, insulation and position within the structure. Some aluminium-backed insulating and construction materials contribute up to 20 dB of loss.

TABLE 2

UHF signal attenuation (dB) through timber-framed buildings*

Building condition		Frequency (MHz) and polarization (Horizontal: H, Vertical: V)			
Exterior	Insulation (non-metallic type)	860 H	860 V	1 550 V	2 569 V
Wood siding	Ceiling only	4.7	2.9	5.0	5.8
	Ceiling and wall	6.3	4.5	6.6	7.4
Brick veneer briques	Ceiling only	5.9	4.1	6.2	7.0
	Ceiling and wall	7.5	5.7	7.8	8.6

* The Table is for rooms located near to the exterior wall; for interior rooms, 0.6 dB should be added.

Measurements of building entry loss using 18 to 20 m towers to simulate a satellite transmitter were performed in the bands 700 MHz to 1.8 GHz and 500 MHz to 3 GHz to determine the mean loss and spatial variability in a variety of buildings. There are insufficient data to give precise prediction methods, but the data in Tables 3 to 5 are indicative.

TABLE 3

**Signal distributions at the average position and best position within buildings
(over the frequency range 700 to 1 800 MHz)**

Building number	Construction	Elevation angle	Average position		Best position	
			Mean loss (dB)	Standard deviation (dB)	Mean loss (dB)	Standard deviation (dB)
1	Corner office, large windows, single-story building. Concrete block, plasterboard, double-glazing. Concrete roof on steel beams	27.5° (line-of-sight (LoS) through window, azimuth angle between wall and LoS is 50°)	7.9	5.5	4.2	4.2
2	Small room with windows being 5/8 of exterior wall	18° (line-of-sight through window, azimuth angle between wall and LoS is 50°)	9.1	4.4	5.4	3.7
3	Corner foyer, large reflective glass door in half of one exterior wall. External walls concrete, internal walls plaster-board on metal frame	16° (line-of-sight through window, 45° azimuth angle between one wall and LoS, both exterior walls illuminated by transmitter)	15.4	8.4	9.7	6.7

TABLE 3 (*end*)

Building number	Construction	Elevation angle	Average position		Best position	
			Mean loss (dB)	Standard deviation (dB)	Mean loss (dB)	Standard deviation (dB)
4	Sheet metal shack with plywood interior. One small unscreened window on each of two sides, metal-covered door	25° (azimuth angle between wall and LoS is 60°)	9.7	6.3	5.2	4.9
5	Two-story wood-side house, rockwool insulation (walls and attic); gypsum board, no metallic heat-shield. No metallic screens on windows. Wood-shingled roof	25° (azimuth angle between wall and LoS is 45°)	9.0	4.5	5.4	3.7
6	Empty sheet-metal mobile trailer home, metal frame windows with metal screens	25° (azimuth angle between wall and LoS is 45°)	24.9	3.8	19.8	3.4

TABLE 4

**Median loss at the average position and best position within buildings
as a function of frequency**
(Construction details and elevation angle as in Table 3)

Building number	Average position	Best position
(As in Table 3)	750-1 750 MHz	750-1 750 MHz
1	5-11 dB	2-6 dB
2	5-14 dB	2-5 dB
3	17-18 dB	12-13 dB
4	9-11 dB	5-6 dB
5	5-11 dB	3-5 dB
6	20 to > 24 dB	16-22 dB

TABLE 5

**Signal distributions at the average position within buildings
(estimated over the frequency range 500-3 000 MHz)**

Building number	Construction	Elevation angle (degrees)	Average position	
			Mean loss (dB)	Standard deviation (dB)
1	Entry lobby in single storey building – concrete tilt wall, tar roof	18	13	10
2	Office in single storey building – block brick, tar roof	38	9	7
3	Two-storey wood frame farmhouse, metal roof, no aluminium heat-shield	33	5	4
4	Hallway and living room of two-storey woodframe house, metal roof, aluminium heat-shield	41	19.5	12
5	Motel room in two-storey building, brick with composite roof	37	13	6
6	Lobby of two-storey building, glass and concrete, tar roof	26	12	5

In these measurements, the first three buildings had elevation angles such that the room was illuminated through a window with a direct LoS from the transmitter. The elevation angles were below 30° to allow side illumination of the buildings.

In the case of building number 3 in these tables, losses through the reflective glass door were about 15 dB greater than when the door was open.

The results of another study are similar, with mean attenuation levels (in the frequency range 500 to 3000 MHz) varying between 5 dB for a woodframe house with metal roof and no aluminium heat-shield, to 20 dB for a similar house with an aluminium heat-shield. Table 5 shows a summary of the measured mean attenuation values.

Note that for some of the measurements, values obtained near a window or open door are included in the averaging. In the motel (building 6), attenuation when the direct path penetrated a brick wall was 15 to 30 dB below the LoS value. Levels inside building 4 varied from 25 to 45 dB below the LoS value, due to the metal roof and aluminium heat-shield.

Note also that the measurements were on stationary paths. There is evidence that close-in multipath effects will give rise to fluctuations in received signal level should the transmitter or receiver move.

This has implications particularly for low-Earth orbit (LEO) systems where the transmitter is moving rapidly with respect to the receiver.

The measurements indicate that attenuation increases with frequency by about 1 to 3 dB/GHz in buildings 1, 2, 4, and 6, by 6 dB/GHz in the least attenuating building (building 3), and shows almost no change with frequency in the glass-walled building 5. Since the values given above are averaged over the frequency range 500 MHz to 3 GHz, they are expected to be slightly optimistic for the 1 to 3 GHz range.

For the six buildings identified in Table 5, 1.6 GHz and 2.5 GHz measurements were performed and analysed to determine the median, 5% and 95% levels of relative signal loss when the antennas were moved horizontally over multiple 80 cm intervals. The buildings were illuminated from the side, and the signals received inside the outside wall (one-wall entry). Azimuthally omnidirectional antennas were used to receive the transmitted signals. Statistics derived from these measurements are summarized in Fig. 1. These data indicate the magnitude and variations of fading that are possible for signal transmission through building walls. Note that on occasions, multipath conditions yield relative signal levels in excess of 0 dB.

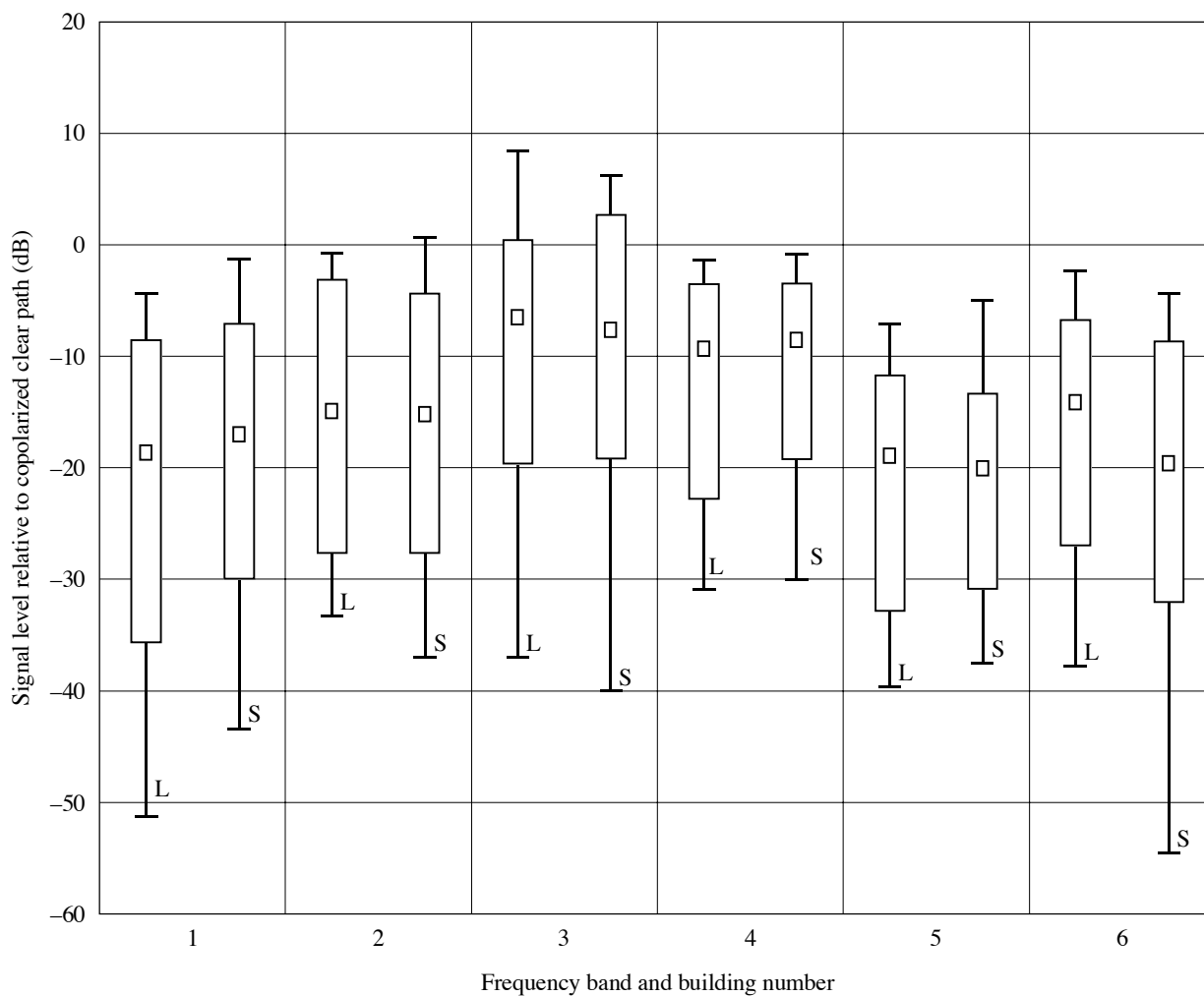
None of the available measurements at frequency bands below 3 GHz provides information for elevation angles above 41°. However, the large losses through metal structures (building 6 in Tables 3 and 4; building 4 in Table 5) suggest that attenuation for a direct path through a metal roof will be of the order of 20 dB. The losses of 15 to 30 dB for a brick wall in building 4 of Table 5 are relevant for higher elevation angles as well.




Studies of terrestrial propagation within buildings indicate that at 2 GHz in an office building, the loss (dB) though floors is given by $15 + 4(n - 1)$ where n is the number of floors penetrated. For a residential building, the loss is typically 4 dB per floor, which serves to estimate the additional loss of a satellite signal entering from a high elevation angle and passing downwards through a building.

The elevation and azimuth angle dependencies of building entry loss in the 5 GHz band were measured at different positions within an eight-storey building on three different floors. A helicopter was used to simulate a satellite transmitter. The received signal was continuously recorded, as well as the position of the helicopter by means of a differential global positioning system (GPS) receiver. The experimental conditions and averaged measurement results are summarized in Table 6. The behaviour of the building entry loss with respect to path elevation angle is shown in Fig. 2, and the behaviour with respect to azimuth in Fig. 3 for elevation angles of 15° and 30°.

The elevation angle dependence was also measured in the 5 GHz band at two different elevation angles by using high-rise buildings to simulate the reception of satellite signals. In an office-type room, the measured medians of the excess building entry loss were 20 dB and 35 dB for elevation angles of 15° and 55°, respectively.

FIGURE 1

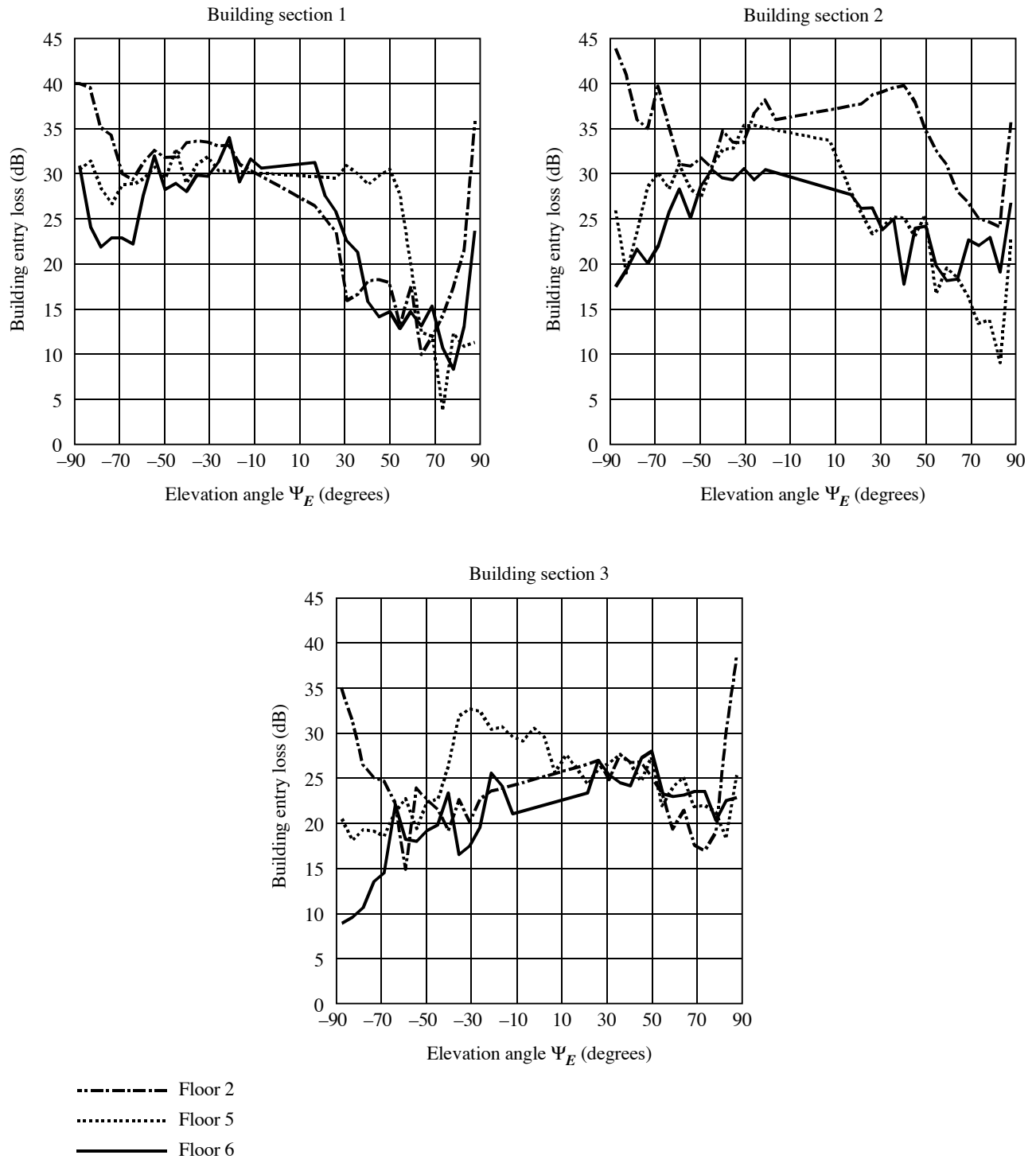


 Nominal range of measured values
 95% - 5%
 Median

Median, 5% and 95% levels of building entry power loss relative to unobstructed LoS at 1.6 GHz and 2.5 GHz for the six buildings identified in Table 5 (designated by 1 to 6 in the Figure). For each building, the 1.6 GHz (L) and 2.5 GHz (S) statistics are shown separately.

FIGURE 2

Building entry loss at 5.1 GHz at sections 1, 2 and 3 for floors 2, 5 and 6. The angle Ψ_E is positive-defined when looking to the north and negative-defined to the south
 $|\Psi_E| = 90^\circ - \epsilon$ where ϵ is the elevation angle



Building section 1: rooms with windows facing helicopter transmitter.

Building section 2: centre of corridor.

Building section 3: rooms with windows not facing helicopter transmitter.

FIGURE 3

Building entry loss at 5.1 GHz for elevation 15° and 30° at the four different indoor antenna positions. Numbers 1 and 2 are located close to an outer wall, whereas numbers 3 and 4 are located in the corridor

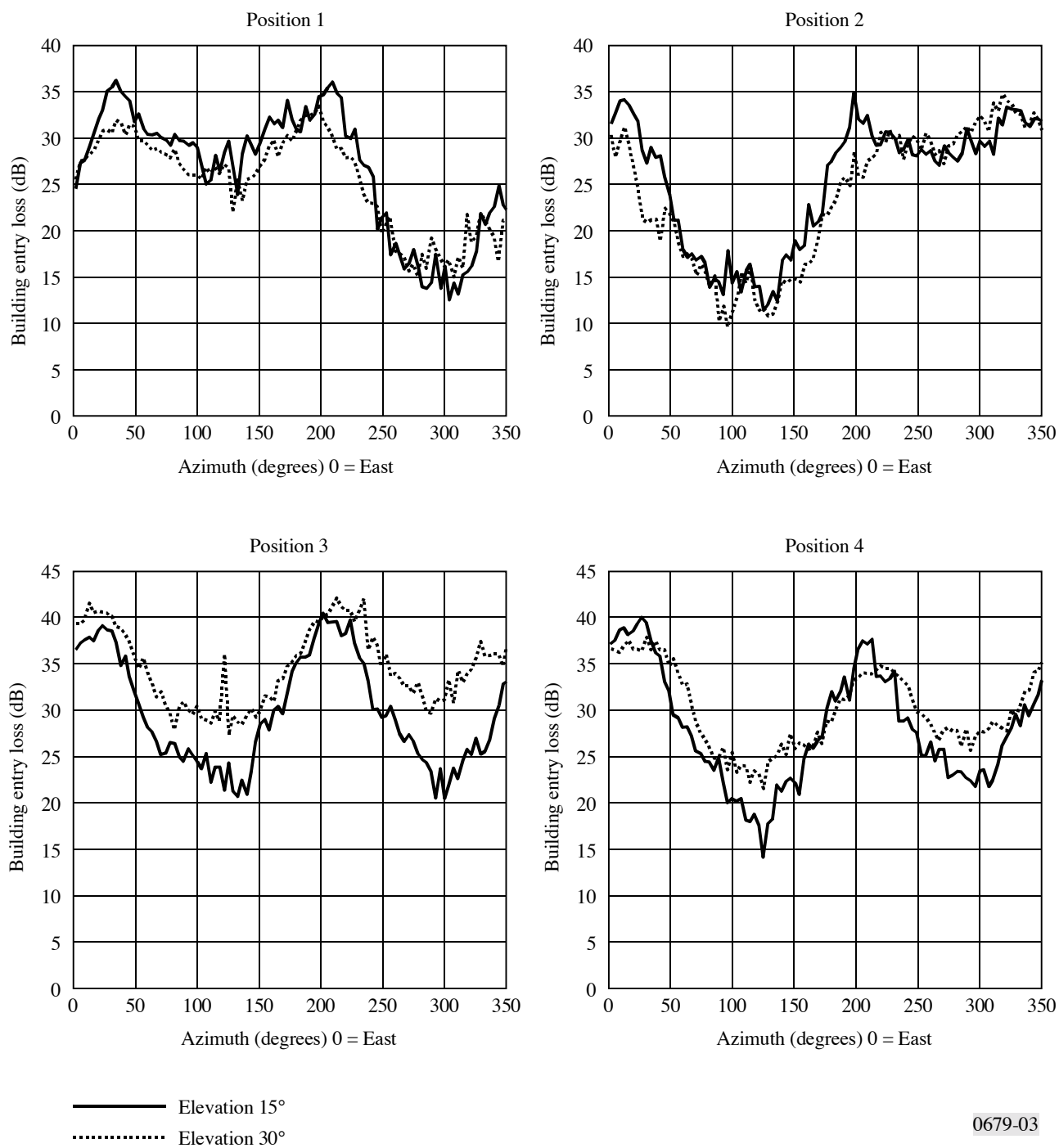


TABLE 6

Average median building entry loss and observed range of the median building entry loss measured at 5.1 GHz for different positions in an office building

	Type of measurements (helicopter trajectory)	Average of the median building entry loss for different receiver positions in the building (dB)	Observed range of the median building entry loss (dB)
Eight-storey building with seven storeys above ground and one extra storey placed on the former roof, brick-walls and windows placed in strips: behind the brick-wall there is a 10 cm thick concrete wall; windows made of two layers of plain non-thermal glass, storeys separated by 3.5 m with 2.5 m from floor to ceiling, two layers of plaster with wooden laths in between separate the rooms; interior walls facing the corridor are in most cases made of glass, rooms commonly furnished with desks and bookshelves; each storey has three sections, a corridor with office rooms at the sides	Elevation angle measurements (linear, perpendicular to the long side of the building)	19.1	~ 5-45
	Azimuth angle measurements (circular at elevation angles of 15° and 30°)	22.3	~ 10-42

4.2 Vehicle entry loss

Measurements of signal penetration into vehicles are quite scanty, and have been obtained by using ground-based techniques similar to those described above. One set of measurements was made at 1 600 MHz using simulated path elevation angles from 8° to 90°, two different antennas (microstrip patch and quadrifilar helix), different types of vehicles (which were mounted on a rotating turntable to evaluate signal level as a function of direction of arrival), and different positions of the terminal user within the vehicle. Data were collected with the vehicle windows down. Typical excess path losses (defined as the measured mean signal level inside the vehicle minus the median fade level observed in open-field measurements with the same antenna and body position used in the in-vehicle measurements) were found to range from 3 to 8 dB at the median, and from 4 to 13 dB at the 90th percentile level.

General observations and conclusions obtained from these data are:

- the signal level inside the vehicles was found to be Rayleigh distributed, implying that no direct LoS propagation path typically exists, and that the signal power is coupled via multipath scatter from edges of vehicle openings (e.g. windows);
- losses at the 90th percentile are 15-20 dB over all path elevation angles;
- loss is only weakly dependent on path elevation angle, but the elevation-angle dependence is different for head-level and hip-level antennas;
- vehicle type has no significant effect on signal penetration loss;
- the position of the terminal user inside the vehicle has no significant effect on loss;
- median excess path loss (with respect to open-field measurements) is log-normally distributed;
- the patch antenna indicates less path loss than a head-level antenna (because the higher directivity causes higher open-field losses, which are not made very much worse when the antenna is inside the vehicle); and
- at an 8° elevation angle, the all-vehicle average median excess path loss was found to be 3.7 dB for a head-level antenna, which compares to a median loss of 3.2 dB at 900 MHz reported for a horizontal path into a large sedan vehicle.

These results may be assumed to represent current general expectations for signal penetration into vehicles.

4.3 Reflections and shadowing by buildings

Measurements obtained by transmitting circularly-polarized FM sound broadcast signals at 839 MHz and 1 504 MHz from a tall tower show that at an elevation angle near 20°, location-to-location variations in field strength near street level in an urban area approach 15 dB at 839 MHz and 18 dB at 1 504 MHz. The fluctuations are practically the same for reception with either vertically- or horizontally-polarized antennas. Sound quality is barely impaired by the field-strength variations under multipath conditions, even in narrow and unfavourably-oriented streets.

In suburban and rural areas, reflections from the ground can be a factor in determining the preferred polarization, as the ground-reflected vertically-polarized wave experiences a deep null at the pseudo-Brewsters angle but the horizontally-polarized wave does not. Thus the horizontally-polarized ground-reflected wave will usually be stronger than the vertical wave for the smooth-Earth case, and the sum of the direct and ground-reflected waves will result in both deeper nulls and higher peaks.

5 Statistical distribution of signal level for large areas

A broadcasting satellite must serve a large area, preferably with the same quality of service throughout for the same time percentage. However, portions of the service area (e.g. within different climatic zones) may be affected differently by certain propagation effects. Such differences can be characterized with coordinated measurements performed at several locations distributed over the service area. Such data are useful both for evaluating subscriber equipment requirements and for determining interference conditions at the borders of the service area, but these data are scarce.

Available data show that the joint probability of occurrence of rainy conditions at different locations is several per cent for separations up to 500 km, and that statistical independence cannot be assumed for separations less than about 800 km. For pairs of sites separated by 200 km, the joint probability for rainfall rates in excess of 5 mm/h can be about five times the probability obtained by assuming statistical independence.

6 Statistical distributions and frequency correlation of signals

Measurements obtained by transmitting a 567.25 MHz signal from a 515 m tower to simulate a satellite signal have shown that, for the vast majority of receiver locations, the distributions of instantaneous values of signal envelope are close to a log-normal distribution. If obstructions by local objects introduce attenuation of more than 15 dB with respect to the median level, the distributions of instantaneous values approximate a Rayleigh distribution.

In the same experiment, the frequency correlations between signals with frequency separations of 0.15 MHz, 0.5 MHz, 1.0 MHz, 2.2 MHz, 4.4 MHz and 6.5 MHz were also measured. It was observed that the frequency correlation decreases as the frequency separation increases and is only incidentally and slightly affected by the elevation angle.
