International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R P.679-4
(07/2015)

Propagation data required for the design of broadcasting-satellite systems

P Series
Radiowave propagation

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SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
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***Note**: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2015

RECOMMENDATION ITU-R P.679-4*

Propagation data required for the design of broadcasting-satellite systems

(Question ITU-R 206/3)

(1990-1992-1999-2001-2015)

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;

e) that Recommendation ITU-R P.2040 provides guidance on the effects of building material properties and structures on radiowave propagation,

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.

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* Radiocommunication Study Group 3 made editorial amendments to this Recommendation in the year 2019 in accordance with Resolution ITU-R 1.

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 μs	0.25 μs	0.028 μs	0.0025 μs
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	$< 1 \times 10^{-4}$ 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/m^2, 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

Material relating to building entry loss can be found in Recommendation ITU-R P.2040.

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 excess 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.