



Recommendation ITU-R P.1407-6
(06/2017)

**Multipath propagation and
parameterization of its characteristics**

P Series
Radiowave propagation



International
Telecommunication
Union
Documents
Document Sharing Hub

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from <http://www.itu.int/ITU-R/go/patents/en> where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Recommendations

(Also available online at <http://www.itu.int/publ/R-REC/en>)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.

Electronic Publication
Geneva, 2017

© ITU 2017

All rights reserved. No part of this publication may be reproduced, by any means whatsoever, without written permission of ITU.

RECOMMENDATION ITU-R P.1407-6*

Multipath propagation and parameterization of its characteristics

(Question ITU-R 203/3)

(1999-2003-2005-2007-2009-2013-2017)

Scope

Recommendation ITU-R P.1407 describes the nature of multipath propagation and defines the appropriate parameters for the statistical description of multipath effects, and provides examples of correlation effects among multiple propagation paths and their computation.

Keywords

Delay profiles, Azimuth/Elevation angle profiles, Directional power-delay profile, Doppler, total power, multipath components.

The ITU Radiocommunication Assembly,

considering

- a) the necessity of estimating the effects of multipath on services employing digital systems;
- b) that it is desirable to standardize the terminology and expressions used to characterize multipath,

recommends

- 1 that, to describe the concepts of multipath in a consistent manner, the terms and definitions given in Annex 1 should be employed;
- 2 that the correlation concepts of Annex 2 should be used to analyse the effects of multiple-input, multiple-output (MIMO) systems;
- 3 that for the generation of wideband channel, models in Annex 3 should be used to evaluate the performance of communication systems.

Annex 1**1 Introduction**

In radio systems with low antenna heights, there are often multiple indirect paths between the transmitter and receiver due to reflections from surrounding objects, in addition to the direct path when there is line-of-sight. Such multipath propagation is particularly significant in urban environments, where the sides of buildings and paved road surfaces provide strong reflections. As a result, the received signal consists of the summation of several components having various amplitudes, phase angles and directions of arrival.

* Radiocommunication Study Group 3 made editorial amendments to this Recommendation in April 2015 in accordance with Resolution ITU-R 1.

The resulting spatial variability of signal strength can be viewed as having two regimes:

- a) rapid fading which varies over distances of the order of a wavelength due primarily to changes in phase angles of different signal components;
- b) slow fading which varies over larger distances due primarily to changes in shadowing loss by surrounding objects.

In addition, the various signal components can be Doppler shifted by different amounts due to the movement of the mobile or of reflecting objects such as vehicles.

The multipath mobile channel can be characterized in terms of its impulse response which varies at a rate dependent on the speed of the mobile and/or the scatterers. Therefore, a receiver has to be able to cope with the signal distortion arising from echoes in the channel as well as the rapid changes in the nature of this distortion. Such characteristics of the mobile radio channel are described by the power delay profiles and the Doppler spectra which are obtained from wideband channel sounding measurements.

Signals transmitted to and from moving vehicles in urban or forested environments exhibit extreme variations in amplitude due to multiple scattering. Fades of 30 dB or more below the mean level are common. The instantaneous field strength when measured over distances of a few tens of wavelengths is approximately Rayleigh-distributed. The mean values of these small sector distributions vary widely from area to area, depending on the height, density and distribution of hills, trees, buildings and other structures.

Physically, multipath propagation parameters are multipath number, amplitude, path-length difference (delay), Doppler shift and arrival angle. These parameters can be characterized from a series of complex impulse responses over a short distance or time interval that can be used to estimate the delay-Doppler spread function representing the multipath phenomenon in the three dimensions of excess delay, Doppler frequency and power density. The delay-Doppler spread function defines a linear transversal filter whose output is the sum of multiple delayed, attenuated and Doppler-shifted replicas of the input signal. This formulation is useful for realizing a hardware simulator in the form of a dynamic transversal filter. The delay-Doppler spread function is used to estimate the power delay profile and the Doppler spectrum, which can be related to the coherence time of the channel. Alternatively, the Fourier transform of the time variant complex impulse response results in the time variant complex frequency response whose amplitude vs frequency characteristics define the multipath frequency selectivity, which is related to the correlation bandwidth and whose time variability gives the fading characteristics at a particular frequency.

Definitions of small-sector (or small-scale) channel parameters are given in §§ 2, 3 and 4. Statistics of small-scale parameters are subsequently used to produce cumulative distribution functions (CDFs). The medium-scale CDF covers a particular route of measurement, which is of the order of tens to hundreds of metres. The combined data set from a number of medium-scale routes is considered to be a large-scale or global characterization, which is representative of the surveyed environment, e.g. hilly terrain, urban, suburban, indoor large rooms, corridors, etc.

2 Parameters of delay profiles

2.1 Definitions of power delay profiles

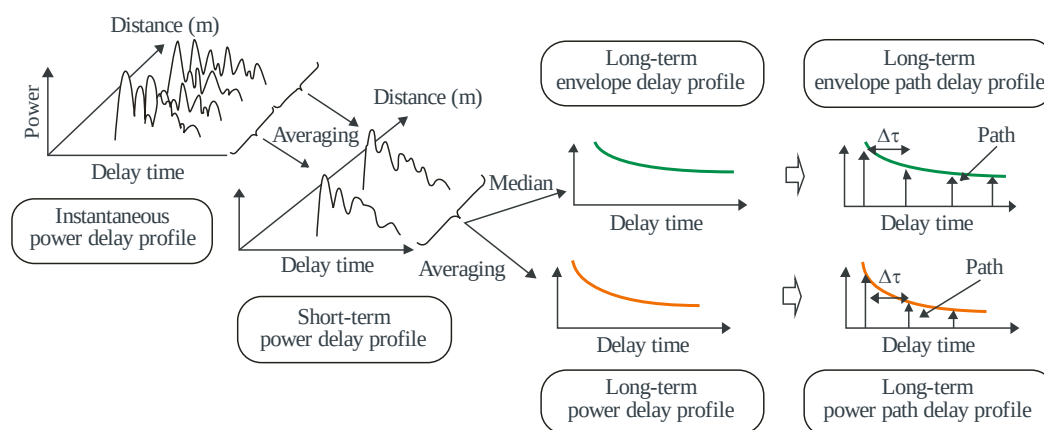
The appropriate parameters for the statistical description of regarding multipath delay time can be computed from any of three types of power delay profiles: the instantaneous power delay profile; short-term power delay profile; or long-term power delay profile, which are either time averages obtained when the receiver is stationary and represent variations in the environment, or spatial averages obtained when the receiver is in motion.

Definitions of power delay profiles are given as shown in Fig. 1.

The instantaneous power delay profile is the power density of the impulse response at one moment at one point.

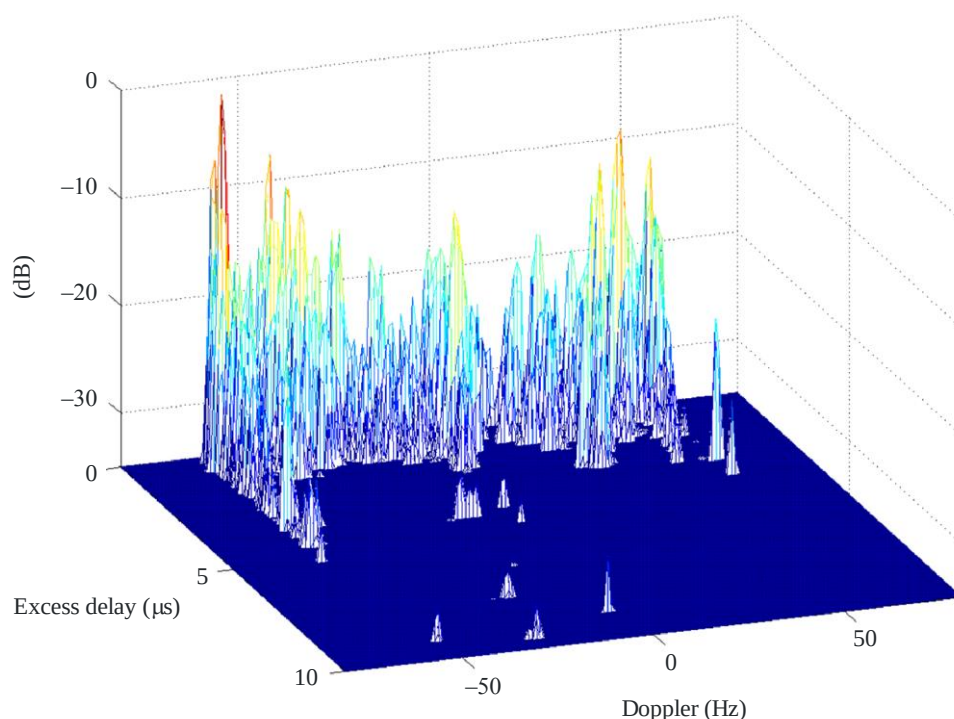
The short-term (small-scale) power delay profile is obtained by spatially averaging the instantaneous power delay profiles over several tens of wavelengths within the range where the same multipath components are maintained in order to suppress the variation of rapid fading. Alternatively, it can be obtained from the delay-Doppler spread function shown in Fig. 2A by taking the sum of the magnitude squared along the Doppler frequency shift axis, as illustrated in Fig. 2B.

FIGURE 1
Definition of power delay profiles



P.1407-01

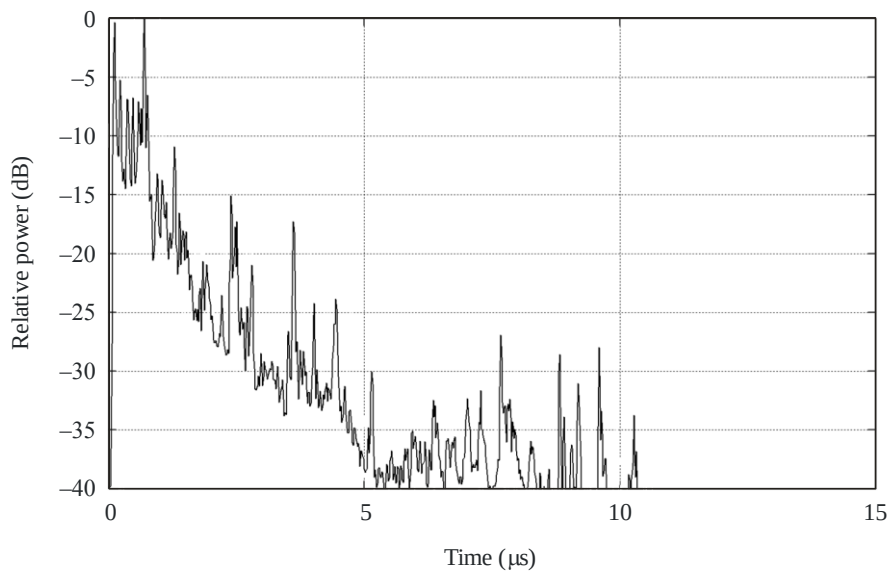
FIGURE 2A
Delay-Doppler spread function



P.1407-02a

FIGURE 2B

Relative power vs. time response



P.1407-02b

The long-term power delay profile is obtained by spatially averaging the short-term power delay profiles at approximately the same distance from the base station (BS) in order to suppress the variations due to shadowing.

Long-term power delay profiles with a discrete excess delay time normalized by time resolution $1/B$, where B is the bandwidth, are defined as long-term power path delay profiles, instead of continuous power delay profiles.

On the other hand, the long-term envelope delay profile is the median value of the short-term power delay profiles at approximately the same distance from the base station; it expresses the shape of the delay profile at the area considered.

2.2 Definitions of statistical parameters

The appropriate parameters for the statistical description regarding multipath delay time are given below. The *average delay* is the power weighted-average of the excess delays measured and is given by the first moment of the power delay profile (the square of the amplitude of the impulse response).

The *r.m.s. delay spread* is the power weighted standard deviation of the excess delays and is given by the second moment of the power delay profile. It provides a measure of the variability of the mean delay.

The *delay window* is the length of the middle portion of the power delay profile containing a certain percentage (typically 90%) of the total power found in that impulse response.

The *delay interval* is defined as the length of the impulse response between two values of excess delay which mark the first time the amplitude of the impulse response exceeds a given threshold, and the last time it falls below it.

The *number of multipath or signal components* is the number of peaks in a power delay profile whose amplitude are within A dB of the highest peak and above the noise floor.

Definitions of the statistical parameters are given with reference to Figs 3A and 3B. It should be noted that the power delay profiles in the figures are represented in the decibel scale, however, the power summation equations are in linear units of power.

2.2.1 Total power

The *total power*, p_m , of the impulse response is:

$$p_m = \int_{t_0}^{t_3} p(t) dt \quad (1)$$

where:

- $p(t)$: power density of the impulse response in linear units of power
- t : delay with respect to a time reference
- t_0 : instant when $p(t)$ exceeds the cut-off level for the first time
- t_3 : instant when $p(t)$ exceeds the cut-off level for the last time.

2.2.2 Average delay time

The average delay, T_D , is given by the first moment of the power delay profile:

$$T_D = \frac{\int_0^{\tau_e} \tau p(\tau) d\tau}{\int_0^{\tau_e} p(\tau) d\tau} - \tau_a \quad (2a)$$

where:

- τ : excess time delay variable and is equal to $t - t_0$
- τ_a : arrival time of the first received multipath component (first peak in the profile)
- $\tau_e = t_3 - t_0$.

In discrete form with time resolution $\Delta\tau$ ($= 1/B$), equation (2a) becomes:

$$T_D = \frac{\sum_{i=1}^N \tau_i p(\tau_i)}{\sum_{i=1}^N p(\tau_i)} - \tau_M \quad (2b)$$

$$\tau_i = (i - 1) \Delta\tau = (i - 1)/B \quad (i = 1, 2, \dots, N)$$

where $i = 1$ and N are the indices of the first and the last samples of the delay profile above the threshold level, respectively, and M is the index of the first received multipath component (first peak in the profile).

The delays may be determined from the following relationship:

$$t_i(\mu s) = 3.3r_i \quad \text{km} \quad (3)$$

where r_i is the sum of the distances from the transmitter to the multipath reflector, and from the reflector to the receiver, or is the total distance from the transmitter to receiver for t_{LOS} .

2.2.3 r.m.s. delay spread

The root mean square (r.m.s.) delay spread, S , is defined by the square root of the second central moment:

$$S = \sqrt{\frac{\int_0^{\tau_e} (\tau - T_D - \tau_a)^2 p(\tau) d\tau}{\int_0^{\tau_e} p(\tau) d\tau}} \quad (4a)$$

In discrete form with time resolution $\Delta\tau$, equation (4a) becomes:

$$S = \sqrt{\frac{\sum_{i=1}^N (\tau_i - T_D - \tau_M)^2 p(\tau_i)}{\sum_{i=1}^N p(\tau_i)}} \quad (4b)$$

2.2.4 Delay window

The delay window, W_q , is the length of the middle portion of the power delay profile containing a certain percentage, q , of the total power:

$$W_q = (t_2 - t_1) \quad (5)$$

whereby the boundaries t_1 and t_2 are defined by:

$$\int_{t_1}^{t_2} p(t) dt = \frac{q}{100} \int_{t_0}^{t_3} p(t) dt = \frac{q}{100} p_m \quad (6)$$

and the power outside of the window is split into two equal parts $\left(\frac{100 - q}{200}\right) p_m$.

2.2.5 Delay interval

The delay interval, I_{th} , is defined as the time difference between the instant t_4 when the amplitude of the power delay profile first exceeds a given threshold P_{th} , and the instant t_5 when it falls below that threshold for the last time:

$$I_{th} = (t_5 - t_4) \quad (7)$$

2.2.6 Number of multipath components

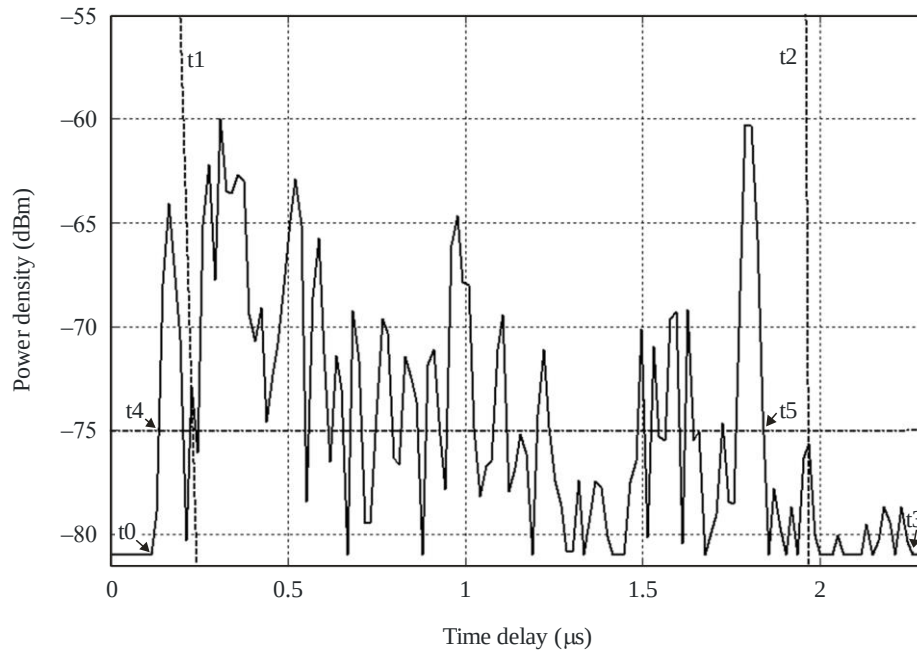
The number of multipath or signal components can be represented from the delay profile as the number of peaks whose amplitudes are within A dB of the highest peak and above the noise floor, as shown in Fig. 3B.

2.2.7 Recommended parameters

Delay windows for 50%, 75% and 90% power, delay intervals for thresholds of 9, 12 and 15 dB below the peak are recommended when analysing data. It is worth noting that the effects of noise and spurious signals in the system (from RF to data processing) can be very significant. Therefore, it is important to determine the noise and/or spurious threshold of the systems accurately and to allow a safety margin on top of that. A safety margin of 3 dB is recommended, and in order to ensure the integrity of results, it is recommended that a minimum peak-to-spurious ratio of, for example, 15 dB (excluding the 3 dB safety margin) is used as an acceptance criterion before an

impulse response is included in the statistics. The threshold used for the identification of the number of multipath components depends on the dynamic range of the measuring equipment; a typical value is 20 dB below the peak level of the delay profile.

FIGURE 3A

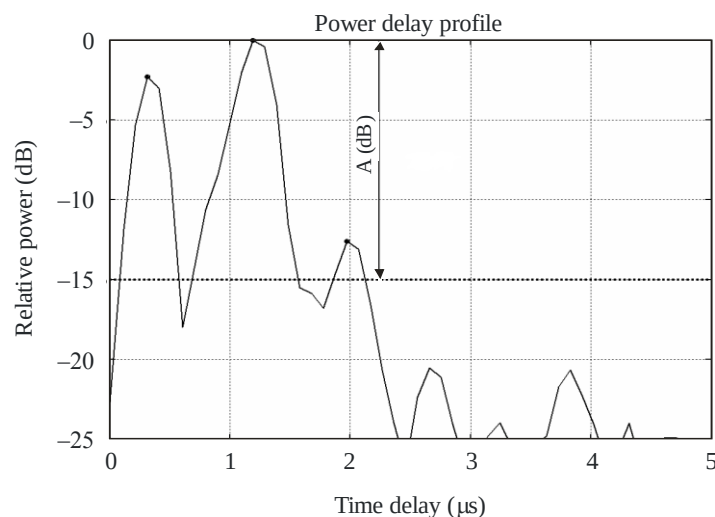


P.1407-03a

Power delay profile illustrating the following parameters: the delay window, W_{90} , containing 90% of the received power is marked between the two vertical dashed lines (t_1 and t_2), the delay interval, I_{15} , containing the signal above the level 15 dB below the peak, lies between t_4 and t_5 . t_0 and t_3 indicate the start and the end of the profile above the noise floor.

FIGURE 3B

Power delay profile indicating multipath components above threshold level



P.1407-03b