International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R P.1321-4
(09/2013)

Propagation factors affecting systems using digital modulation techniques at LF and MF

P Series

Radiowave propagation

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

RECOMMENDATION ITU-R P.1321-4

**Propagation factors affecting systems using digital
modulation techniques at LF and MF**

(Question ITU-R 225/3)

(1997-2005-2007-2009-2013)

Scope

This Recommendation provides information on the characteristics of LF and MF ground-wave and sky-wave propagation which may affect the use of digital modulation methods in those bands.

The ITU Radiocommunication Assembly,

considering

a) that digital modulation methods for sound broadcasting purposes at LF and MF are currently being studied;

b) that information on the propagation characteristics at these frequencies is necessary for use in the design of modulation methods,

recommends

that the information given in Annex 1 should be taken into account in the design of digital modulation methods for broadcasting at MF and LF.

Annex 1

1 Introduction

The majority of broadcasting services in the MF and LF bands are based on the characteristics of the ground-wave propagation mode (see Recommendation ITU-R P.368). The limiting coverage range, during daytime and in the absence of interference, is determined by the intensity of radio noise due to lightning and to man-made sources (see Recommendation ITU-R P.372) and by the required signal-to-noise ratio. During the hours of darkness, ionospheric sky-wave modes become important (see Recommendation ITU-R P.1147). For analogue amplitude modulation, these modes limit the coverage, since the wave-interference between the ground wave and the varying and phase delayed sky-wave modes results in unsatisfactory signal quality. Sky-wave signals from other distant transmissions may also add significant night-time interference, which may also restrict the service coverage to ranges where the ground wave provides a sufficiently strong signal; aspects of interference from other signals are not further considered in this annex.

Digital modulation methods may also be affected by the presence of delayed signal modes, but suitable modulation design may counter or exploit this effect. This annex presents some very simple models for this multipath environment, which are expected to be suitable for the design of modulation methods. Dependent on the modulation method chosen, more detailed prediction methods may be required for service planning purposes.

2   Propagation modes

2.1   Ground wave mode

The ground wave may often not be constant (see § 4). Also as shown in Recommendation ITU-R P.368, the signal amplitude depends on range and the electrical characteristics of the ground. Also the signal amplitude does not remain constant for small changes in location (from several hundred metres).

2.2   Sky-wave modes

During daylight hours, signal attenuation in the lower D-region part of the ionosphere effectively prevents sky-wave propagation. This annex concentrates on the conditions at night when sky-wave propagation may be significant.

The E-layer of the ionosphere decays after sunset, but the critical frequency, foE, will be within the MF broadcast band, at least for times in the first part of the night. Signals at frequencies less than the critical frequency will always be reflected by the E-layer, and multihop reflections will also be supported. Signals at higher frequencies may still be reflected from the E-layer, particularly to longer ranges, but signals will also penetrate the E-layer to be reflected from the higher F-region. Using a simple model for the E-layer, Fig. 1 illustrates the available signal modes for three frequencies in the MF band, showing the way in which mode availability varies with ground range and with time after sunset. These modes will be time delayed compared with the ground wave mode.

Recommendation ITU-R P.1147 provides predictions for the composite signal power for the available sky-wave modes, and thus does not give the necessary information for the relative amplitudes for individual modes. However, Recommendation ITU-R P.684 does provide information, although primarily intended for frequencies less than 500 kHz. In particular, it gives values for the ionospheric reflection coefficient for sunspot minimum conditions, based on experimental results, and on some assumptions, as stated in the Recommendation.

3   Multipath time spread

Using the above simple propagation models, Fig. 2 shows the expected median field strengths and relative time delays for three ranges, 100, 200 and 500 km, and two frequencies, 700 kHz and 1 MHz. The field strengths are for 1 kW e.m.r.p. and do not include the effect of the vertical radiation pattern of the transmitting antenna – this may reduce the levels of the sky-wave signals at the shorter ranges.

The mode shown at 0 ms is for the ground wave, and field strengths are shown for three values of ground conductivity; 5 S/m (sea water), 10^{-2} (good ground), and 10^{-3} (poor ground).

The sky-wave components are marked with the relevant mode and the levels approximately represent the median field strengths four hours after sunset at sunspot minimum.
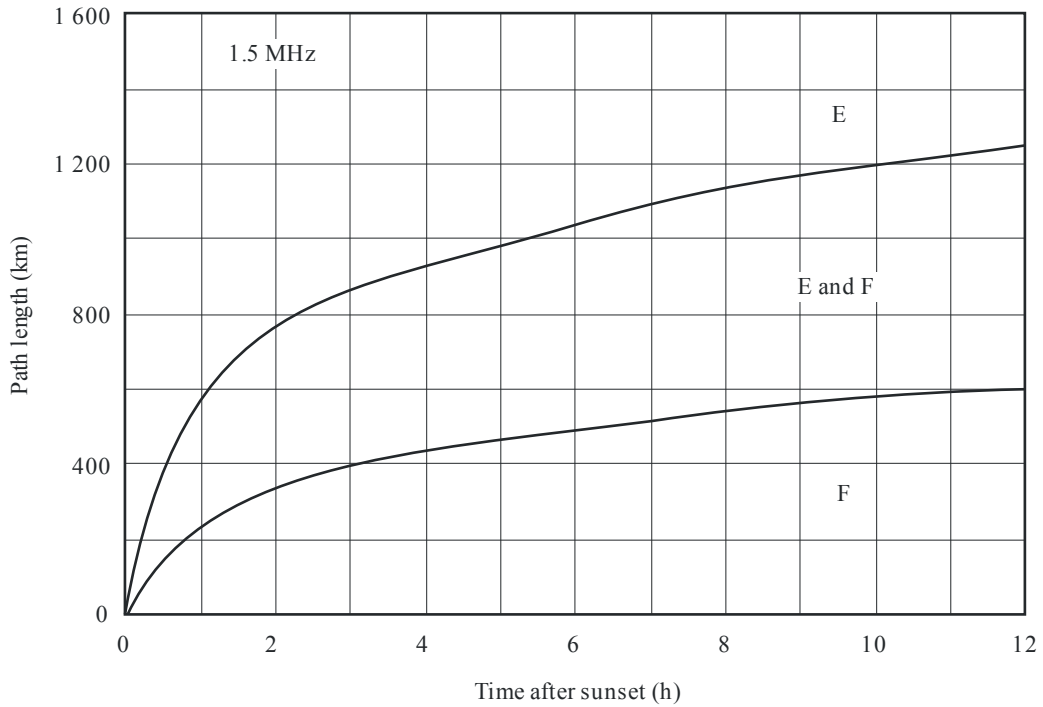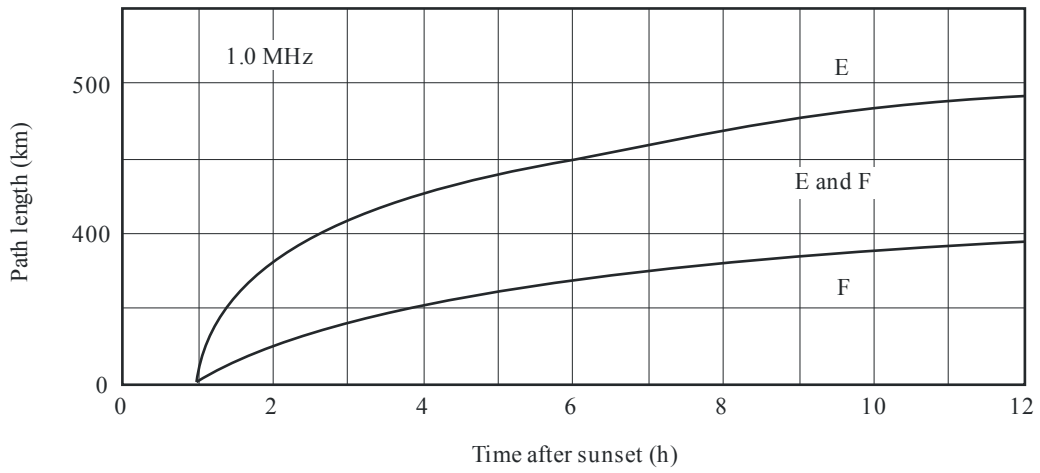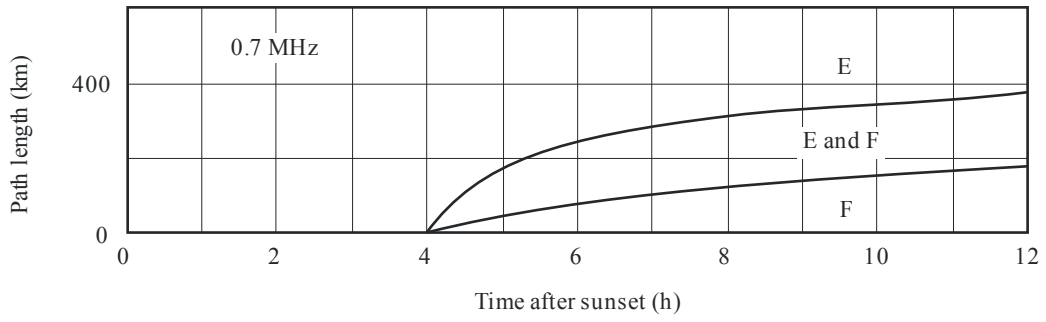
FIGURE 1

Available propagation modes

P.1321-01

FIGURE 2

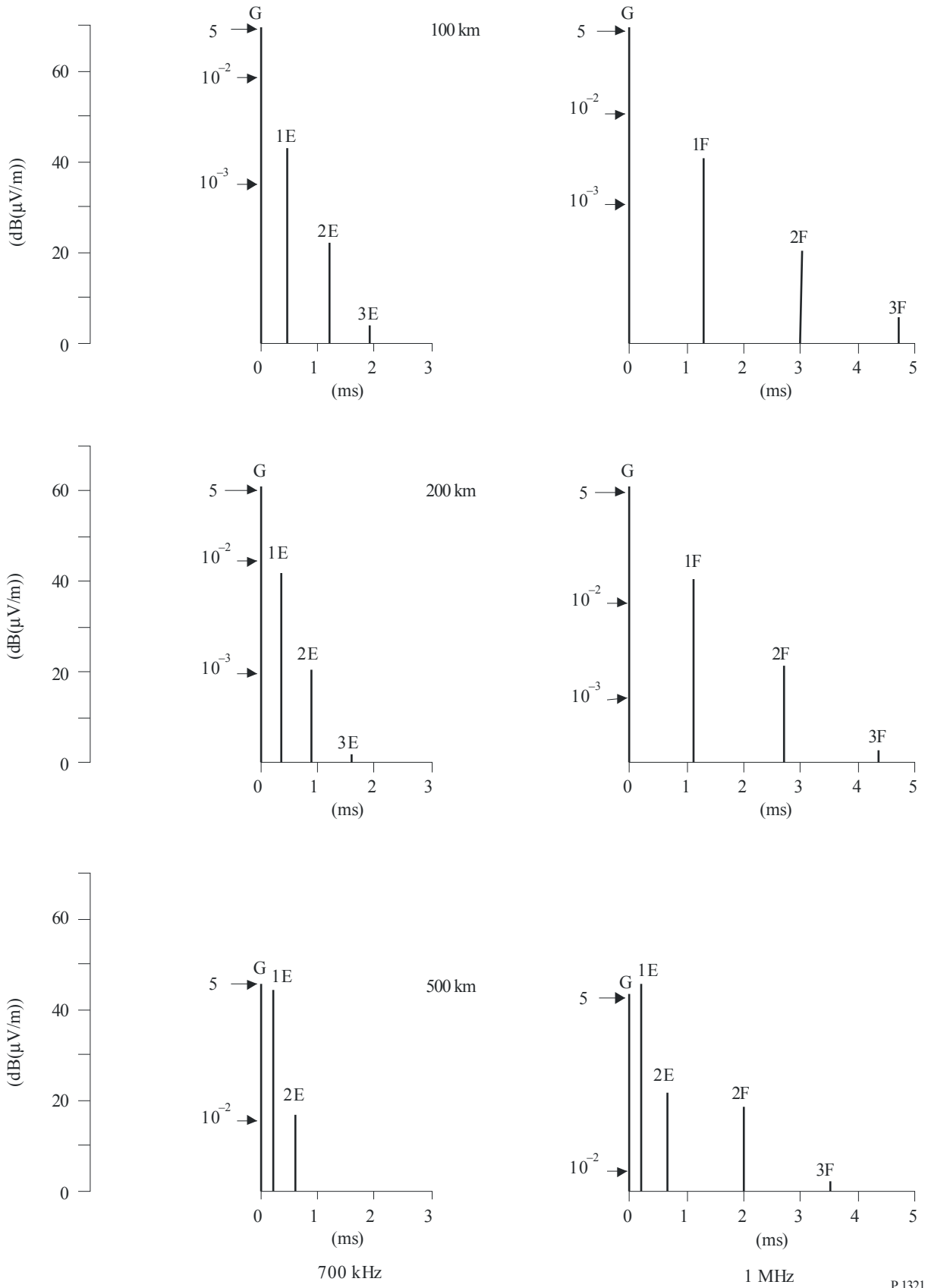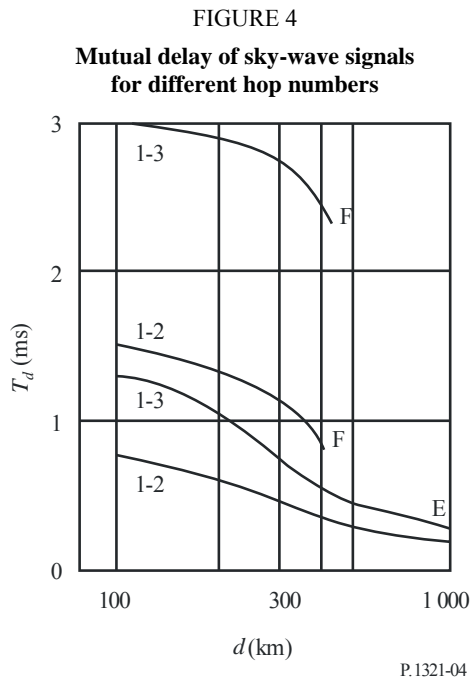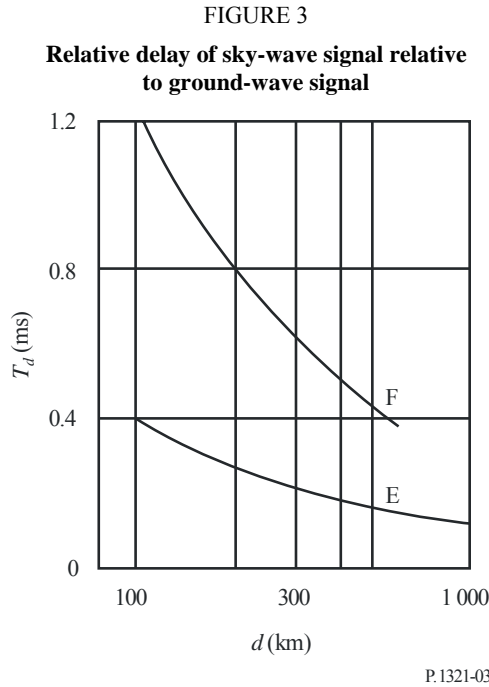**Examples of time delay spread**

P.1321-02

Figure 3 indicates the delay of the one hop E- and F-region sky-wave modes relative to the ground wave for ranges out to 1 000 km, while Fig. 4 gives the relative delays between single and multihop sky-wave modes.

FIGURE 3

Relative delay of sky-wave signal relative to ground-wave signal

P.1321-03

FIGURE 4

Mutual delay of sky-wave signals for different hop numbers

P.1321-04

The range of distances for which the ground and sky-wave signal amplitudes are similar have particular interest since the fading exhibited in this zone is particularly severe. This has been called the "night fading zone" and has often set the limit for the range of good quality MF broadcasting.

4 Variability

4.1 Time-variations signal in daytime

4.1.1 Seasonal variations

The field strength of terrestrial waves can vary with winter temperature. The average annual range (the difference between monthly median field strength in winter and summer months) for 500-1 000 kHz is contained in Table 1 for the Northern Hemisphere latitude where the average January temperature is less than about 4°C.

TABLE 1

Average northern hemisphere January temperature (°C)	4	0	−10	−16
Winter-summer field strength range, u (dB)	4	8	13	15

At LF the range of variation of field strength in average latitudes with a continental climate (as measured in continental Europe and the Siberian region) depends on distance and frequency, dependent on the parameter $q = d \cdot f^{1/2}$, where d is the distance (km) and f is the frequency (MHz). Values of $q < 500$, approximately, characterize the variation for ground waves, and greater values, $q > 500$, concern ionospheric sky waves.

The corresponding formulas for the range of the variation are:

– for paths with a small proportion of woodland:

$$U_{s/w} = 3 + 2 \times 10^{-5} \times q^2 + 0.005q \qquad \text{dB}$$

– for paths with a large proportion of woodland:

$$U_{L/w} = 6.409 \times \ln(q) - 21.124 \qquad \text{dB}$$

Here indexes s/w and L/w mean a small proportion of woodland (approximately up to 30%) and a large proportion of woodland (more than 50%), accordingly.

4.1.2 Day-by-day variations of the hour median

For the value of the root-mean-square (RMS) deviation (σ_L for LF and σ_M for MF) the hourly median field strength from monthly median at LF depends on the path length, while at MF it depends on frequency.

At LF, in medium latitudes with a middle proportion of woodland, this dependence is:

$$\sigma_L = 0.073 \, d^{0.5} + 0.00122 \, d \qquad \text{dB}$$

At MF, the RMS deviation with frequency for paths 20 km to 120 km without division into seasons, is:

$$\sigma_M = 0.0018f + 0.6 \qquad \text{dB}$$

In these equations, σ_L, σ_M are RMS in dB, d is the distance in km, f is the frequency in kHz.

4.2 Variations of a signal in daytime from place to place

At MF, the changes of level of a signal between locations separated by distances of the order of 1 km have similar values of standard deviation in different parts of the world. The probability distribution practically coincides with a log-normal law with a root-mean-square deviation $\sigma = 3.7$ dB, as shown in Fig. 5.

In urban conditions in streets and areas, the standard deviation also is close to 4 dB. In densely built-up parts of a city, especially at small distances from the transmitter (up to 1 km), the standard deviation rises, reaching 7-8 dB. Inside buildings in rare cases additional absorption can reach 20 dB.

4.3 Variations of a signal in night-time

Sky-wave modes will be subject to long-term night-to-night variability where the hourly median values have a log normal distribution with a semi-interdecile range of between 3.5 and 9 dB. Within the hour fading of individual modes also has a log normal distribution; there are few measurement data, but a typical value for the standard deviation of about 3 dB may be assumed. The fading rate is between 10 and 30 fades/h.

For cases when the composite amplitude of the ground wave and sky-wave modes needs to be considered, i.e. in cases where the modes cannot be separated in the receiving system, the fading distribution of the signal is discussed in Appendix 1 to Annex 1.

The frequency shift of sky-wave modes, due to the Doppler effect on reflection from moving ionospheric layers, will be small.

FIGURE 5

The law of distribution of deviations
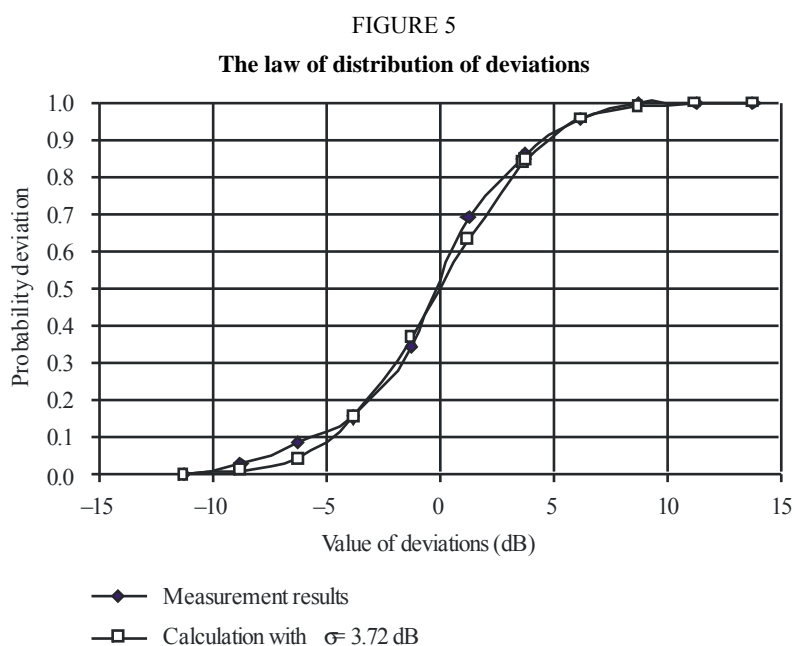
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4.4 The characteristics of excesses and fades in LF and MF ionosphere channels

For analysis and planning of digitally modulated radiocommunication systems in the LF and MF bands, the characteristics of the average values and signal dispersion appear to be insufficiently described. It is necessary to take into account more detailed properties of excesses and fades, in particular the probability distribution of excesses and fade durations need to be understood, at various signal-to-interference levels. The statistical characteristics of excesses and fades were obtained for a two-year period on two links, one LF (1 550 km at 155 kHz) and one MF (860 km

at 539 kHz), and are given below in Appendix 2. The results concern the middle geographical latitudes of the eastern hemisphere and moderate sun-spot activity (SSN ≈ 40).

In Appendix 2, the number of excesses and fades per hour for each link are given in Tables 3 and 4. Figures 6 and 7 show scatter diagrams of the number (%) of median threshold excess durations for each link.

5   Conclusions

Recommendation ITU-R P.1407 identifies a set of parameters for use in describing multipath effects. The "delay window", containing more than say 98% of the total energy, may be determined from inspection of Fig. 2 as less than 3 ms. It may be noted that in some circumstances the initial multipath component will not be that with the greatest amplitude.

Appendix 1
to Annex 1

The composite signal amplitude, e, for the combination of a steady ground wave signal and a log-normally distributed sky-wave signal is obtained by a power summation:

$$e = \sqrt{e_e^2 + e_i^2}$$

where e_e and e_i are the levels of the ground wave and sky-wave components, usually expressed in μV/m.

The sky-wave component e_i has a log normal distribution (see Recommendation ITU-R P.1057, equation (6)). For convenience it is supposed ostensibly that the ground wave component is also log-normally distributed, and the final result is obtained by setting its standard deviation to 0 dB.

The combination of two log-normal distributions is also log-normally distributed where the mean level is the sum of the individual mean levels (i.e. in amplitude, not in decibels) and the variance is the sum of the two variances.

For a log-normal distribution (see Recommendation ITU-R P.1057) the mean and the standard deviation of the signal levels (μV/m) are given by:

$$\text{Mean} = e^m \cdot e^{\sigma^2/2}$$

$$\text{Standard deviation} = \sqrt{e^{2m} \cdot e^{\sigma^2}\left(e^{\sigma^2} - 1\right)}$$

where m is the mean and σ is the standard deviation of the log-normal distribution.

Using these considerations it is possible to evaluate the parameters for the combined distribution. Table 2 gives example results where the standard deviation of the log-normal sky-wave component is 3 dB.

TABLE 2

e_i / e_e	Mean level relative to the mean of the ground wave component	Standard deviation
0.5 (–6 dB)	+1.3 dB	0.72 dB
1 (0 dB)	+4.4	1.35
2 (+6 dB)	+5.7	2.0

Appendix 2
to Annex 1

TABLE 3

Number of excesses and fades per hour on an LF link

	Time of day (hour)								
Threshold level	18	19	20	21	22	23	24	01	02
Median (excess)	2.3	2.7	3.1	3.7	4.1	4.6	4.4	3.9	3.5
L. decile (fade)	1.5	1.75	2	2.3	2.6	2.6	2.3	2	1.7
U. decile (excess)	1.6	1.8	1.9	2.1	2.25	2.4	2.4	2.3	2.2

TABLE 4

Number of excesses or fades per hour on an MF link

	Time of day (hour)									
Threshold level	18	19	20	21	22	23	24	01	02	03
Median (excess)	1.8	2	2.3	2.7	2.9	3.2	3.5	3.5	3	2.7
L. decile (fade)	1.5	1.7	1.9	2.1	2.2	2.4	2.5	2.4	2.3	2.1
U. decile (excess)	1.4	1.5	1.7	1.8	1.9	2	2.1	2.1	2	1.8

Distribution for the median level excess duration in the LF and MF bands

To approximate the statistical characteristics of the median level excess durations in the LF and MF band, the following distribution can be used:

$$P_k = 0.38 \cdot e^{-d\,t^2/r^2} + 0.62 \cdot e^{-0.5\,t^2/q^2} + 0.62 \cdot e^{-b\,t/r} \cdot \left(1 - e^{-0.5\,t^2/q^2}\right) \qquad (1)$$

where t (min) is greater than or equal to 0 and d, b, q and r are selected parameters.

Distribution for the upper decile excess duration and lower decile fading durations in the LF and MF bands

The fading duration probability distribution for the upper and lower decile thresholds is well described by a Gamma distribution:

$$p_G = \frac{\lambda^\alpha}{\Gamma(\alpha)} \cdot t^{\alpha-1} \cdot e^{-\lambda t}, \qquad P_G = \frac{\lambda^\alpha}{\Gamma(\alpha)} \cdot \int t^{\alpha-1} \cdot e^{-\lambda t} \, dt \tag{2}$$

where:

$\qquad\qquad p_G:$ probability distribution

$\qquad\qquad P_G:$ cumulative distribution

$\qquad\qquad t:$ duration (min)

$\qquad\lambda$ and $\alpha:$ selected parameters.

Table 5 below indicates the distribution and parameter values for several threshold levels.

TABLE 5

**Distribution and parameters for several thresholds**

Band	Threshold level	Excess or fading	Distribution	Parameters
LF	Median level	Excess	Equation (1)	$b = 0.32$, $d = 3.0$, $q = 4.0$, $r = 3.8$
LF	Lower decile	Fading	Equation (2)	$\alpha = 2.00$, $\lambda = 0.67$
LF	Upper decile	Excess	Equation (2)	$\alpha = 2.20$, $\lambda = 0.67$
MF	Median level	Excess	Equation (1)	$b = 0.3$, $d = 0.8$, $q = 1.8$, $r = 2.2$
MF	Lower decile	Fading	Equation (2)	$\alpha = 3.30$, $\lambda = 1.13$
MF	Upper decile	Excess	Equation (2)	$\alpha = 2.95$, $\lambda = 0.7$

The experimental data for median values of the excess duration for LF and MF differ insignificantly, by approximately 1 min (5 min for LF and 4 min for MF).
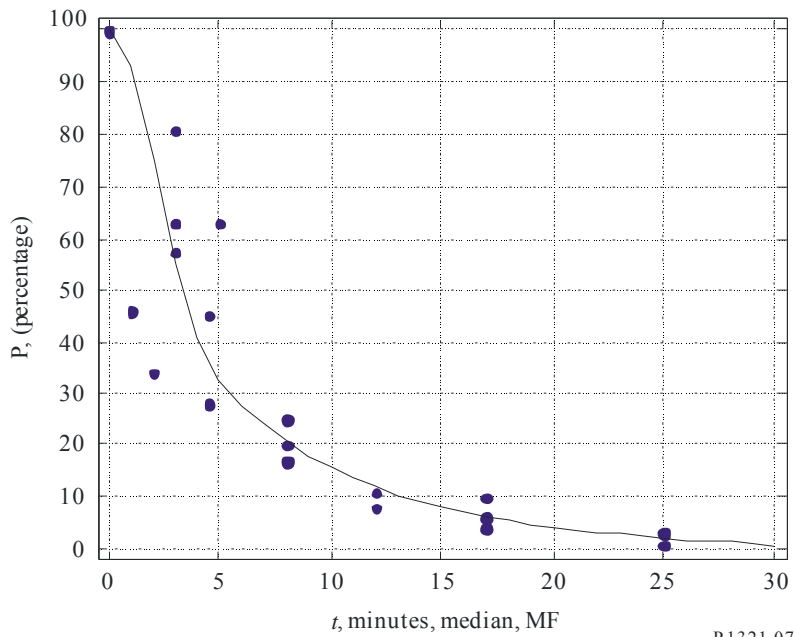
FIGURE 6

**Number of excess durations (%) per hour for medium threshold
on an LF link and integral distribution**

t, minutes, median, LF
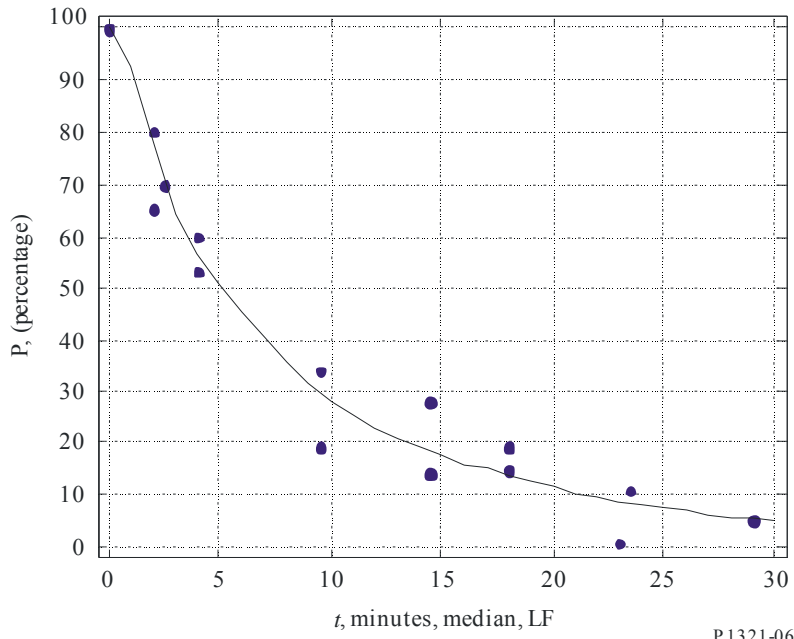
P.1321-06

FIGURE 7

**Number of excess durations (%) per hour for median threshold
on a MF link and integral distribution**

t, minutes, median, MF

P.1321-07