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(05/2000)

Testing of HF modems with bandwidths of up to about 12 kHz using ionospheric channel simulators

F Series

Fixed service

International Telecommunication Union

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

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RECOMMENDATION ITU-R F.1487*, **

TESTING OF HF MODEMS WITH BANDWIDTHS OF UP TO ABOUT 12 kHz USING IONOSPHERIC CHANNEL SIMULATORS

(2000)

Scope

This Recommendation provides methodology for testing of HF ionospheric transmission for systems up to about a 12 kHz bandwidth. This Recommendation also provides comparative testing for HF modems and quantitative testing for HF modems.

The ITU Radiocommunication Assembly,

considering

a) that ionospheric radiocommunication in the HF bands is an economically effective transmission medium for many services requiring beyond line-of-sight operation;

b) that simulation of the ionospheric propagation channel could reduce the time and expense of studying and testing the performance of such service systems;

c) that some administrations have reported good correlation between the results of laboratory tests conducted on simulators and the results of tests of data modems in operation,

recommends

1 that for the simulation of HF ionospheric transmission for systems up to about 12 kHz, the methods described in Annex 1 should be preferred;

2 that the method described in Annex 2 should be referred to for comparative testing of HF modems;

3 that when simulators are used to predict, in a quantitative sense, how well a particular modem may be expected to perform on HF circuits, the representative channel parameters listed in Annex 3 should be considered.

ANNEX 1

HF ionospheric channel simulations

1 Introduction

HF ionospheric radiocommunication is typically characterized by multipath propagation and fading. The transmitted signal usually travels over several paths or modes to the receiver via single and multiple reflections from the E and F layers of the ionosphere. Since the propagation times over the paths are different, the signal at the receiving antenna may consist of several multipath components spread in time over an interval of up to several milliseconds. The average heights of the ionospheric layers may increase or decrease with time, which introduces different frequency (Doppler) shifts on each of the multipath components. The ionosphere is also turbulent which causes Doppler spread (fading) of each component and a resultant fading of the composite received signal. All of these effects produce multiplicative signal distortion and degradation of the performance of communication systems.

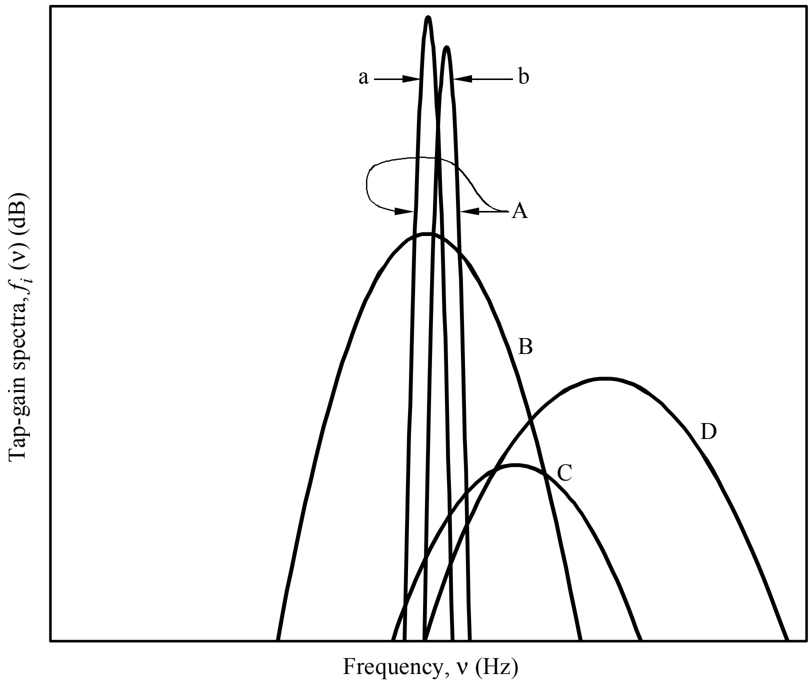
* This Recommendation should be brought to the attention of Radiocommunication Study Group 3.

** Radiocommunication Study Group 5 made editorial amendments to this Recommendation in December 2009 in accordance with Resolution ITU-R 1.

If a continuous wave (CW) signal is transmitted over an HF link the spectra of the received multipath components can appear as shown in Fig. 1. Four paths are present: one-hop E mode (1E), one-hop F mode (1F), two-hop F mode (2F), and a mixed mode (e.g. 1E + 1F). While the two magneto-ionic components (labelled a and b) in the 1E mode have about the same frequency spreads (fading rates), their frequency shifts are significantly different, allowing them to be resolved in frequency. On each of the other three modes, both the spreads and shifts of the magneto-ionic components are essentially the same and they appear as one. The short-term multiplicative distortion characteristics of the HF channel can thus be described in terms of the parameters that specify the signal losses, time-spread and frequency spread characteristics; i.e. the differential propagation times on the several paths, and the signal strengths, frequency shifts, and frequency spreads on each path. These parameters are subject to change on a diurnal and seasonal basis, as well as generally being different on different geographic circuits.

FIGURE 1

Example power spectra for the multipath components of a CW signal



A: Path 1 (1E mode, a and b represent magneto-ionic splitting)
B: Path 2 (1F mode)
C: Path 3 (Mixed mode)
D: Path 4 (2F mode)

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To compare the performance of two or more systems over real HF links, they must be run simultaneously because propagation or channel conditions vary uncontrollably and cannot be repeated at other times or over other links. The use of a channel simulator has the advantages of accuracy, regularity of performance, repeatability, availability, a large range of channel conditions, and lower cost. However, these advantages are limited if the channel model on which the simulator design is based is not valid. This Recommendation describes a stationary Gaussian scatter HF channel model. It is valid for use in 3 kHz channels, and may be applicable to bandwidths up to 12 kHz wide. A practical implementation of this model may operate at baseband (audio) frequencies and thereby act directly on the output of a transmitting HF modem and provide signals directly to a receiving HF modem. However, when considering the performance of HF systems the effect of other system components should always be taken into account (e.g. transmit and receive filters and level or gain control).

2 Gaussian scatter model

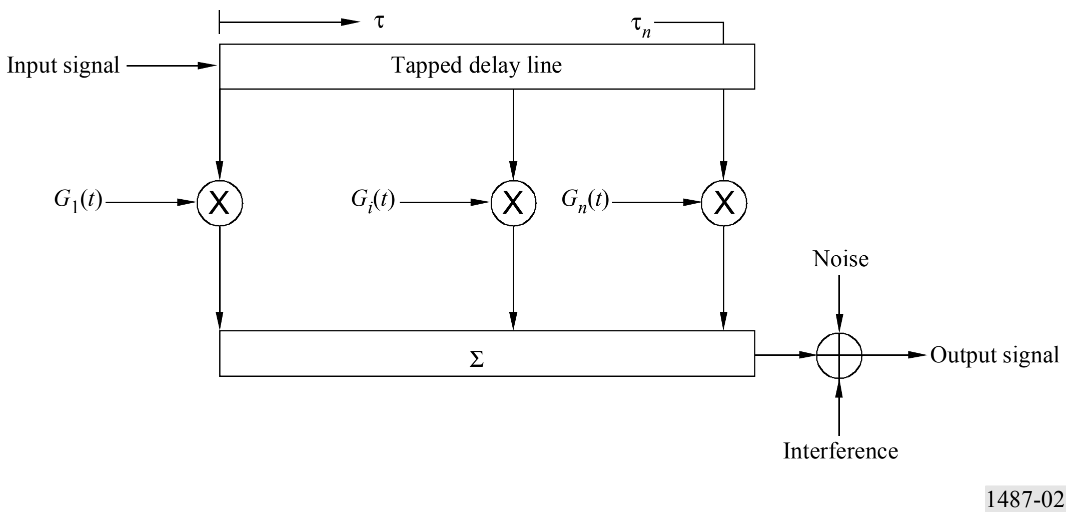
A block diagram of the stationary Gaussian scatter HF ionospheric channel model is presented in Fig. 2. This is commonly known as Watterson model. The input (transmitted) signal is fed to an ideal delay line and delivered at several adjustable taps, numbered 1, 2, ..., i, ..., n, one for each ionospheric propagation mode or path. At each tap, the delayed signal is modulated in amplitude and phase by an appropriate complex random tap-gain function, $G_i(t)$. The delayed and modulated signals are summed with additive noise (Gaussian, atmospheric, and/or man-made) and/or interference (unwanted signals) to form the output (received) signal. For the Gaussian scatter channel model each tap-gain function is defined by:

$$G_i(t) = \tilde{G}_{ia}(t)\ \exp(j\ 2\pi\ \nu_{ia} t) + \tilde{G}_{ib}(t)\ \exp(j\ 2\pi\ \nu_{ib} t) \qquad (1)$$

where, the a and b subscripts identify the two magneto-ionic components that can, in general, be present in each mode or path. The tildes indicate that $\tilde{G}_{ia}(t)$ and $\tilde{G}_{ib}(t)$ are sample functions of two independent complex (bivariate) Gaussian ergodic random processes, each with zero mean values and independent real and imaginary components with equal r.m.s. values that produce Rayleigh fading (i.e. that they are Gaussian scatter functions). The exponential functions in equation (1) are included to provide the required frequency (Doppler) shifts, ν_{ia} and ν_{ib}, for the magneto-ionic components in the tap-gain spectrum.

FIGURE 2

Block diagram of HF ionospheric channel model



Each tap-gain function has a power spectrum, $f_i(\nu)$, that in general consists of the sum of two magneto-ionic components, each of which is a Gaussian function of frequency, ν, as specified by:

$$f_i(\nu) = \frac{1}{\tilde{A}_{ia}\,\sigma_{ia}\sqrt{2\pi}}\ \exp\left[\frac{-(\nu-\nu_{ia})^2}{2\sigma_{ia}^2}\right] + \frac{1}{\tilde{A}_{ib}\,\sigma_{ib}\sqrt{2\pi}}\ \exp\left[\frac{-(\nu-\nu_{ib})^2}{2\sigma_{ib}^2}\right] \qquad (2)$$

where, $\tilde{A}_{ia}$ and $\tilde{A}_{ib}$ are the component attenuations, and the frequency spread on each component is usually determined by $2\sigma_{ia}$ and $2\sigma_{ib}$. Equation (2) is illustrated in Fig. 3a). Six independent parameters specify a tap-gain function and its spectrum: the two attenuations, $\tilde{A}_{ia}$ and $\tilde{A}_{ib}$, the two frequency shifts, ν_{ia} and ν_{ib}, and the two frequency spreads, by $2\sigma_{ia}$ and $2\sigma_{ib}$.

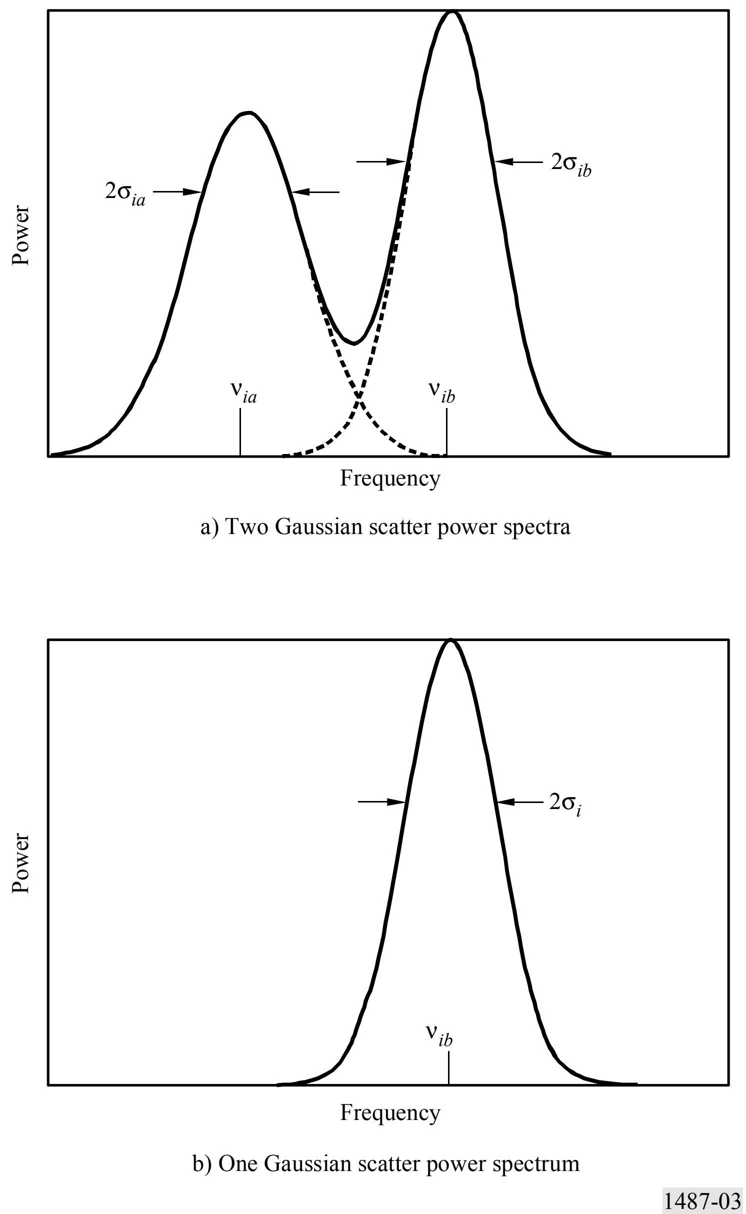
The tap-gain function described by equations (1) and (2) is general in that it applies when the spectra of the two magneto-ionic components are significantly different and the difference in their delays is negligible. Only one of the two terms in equations (1) and (2) is required in the following cases:

– when the frequency shifts and frequency spreads of the two magneto-ionic components are nearly equal, their spectra nearly match, and a single term can be used with the tap-gain spectrum in Fig. 3b);

– when the two magneto-ionic components have a significantly large difference in delay. In this case, separate delay line taps with appropriate spacing should be used, with each of the two corresponding tap-gain functions and spectra consisting of a single term, again as illustrated in Fig. 3b).

FIGURE 3

Tap-gain power spectra in Gaussian scatter model



3 Specular modes

The Gaussian scatter model can accurately represent the majority of typical HF ionospheric links. A specular component in a skywave mode can easily be simulated by adding a non-fading delay tap with the same frequency offset as the corresponding mode spectrum. Thus, in Fig. 3 specular components would appear as Dirac-delta functions at ν_{ia}, ν_{ib} and ν_i, as applicable.

The ground wave present on a short link is essentially non-fading and can also be represented by a non-fading tap at the appropriate group time delay.

4 Models for HF channels with more than 12 kHz bandwidth

While the aforementioned Gaussian scatter model has been validated for use with 3 kHz HF channels, and may be suitable for channels up to 12 kHz wide, its suitability for even wider bandwidths (viz., extended bandwidths between 12 kHz and about 1 MHz) is problematic for at least two reasons. First, the specification of a model to characterize such extended bandwidth channels has proven to be difficult, owing to the lack of channel information for that regime. Secondly, there is paucity of extended bandwidth modems which are most appropriate for validation of the model.

Despite difficulties in generalization, an extension of the 3 kHz channel model is contemplated, based upon a belief that such a model may be required in the near future. Accordingly, studies are being undertaken to accommodate channel bandwidths in excess of about 12 kHz using logical extensions of the present Gaussian model. While the logic is generally defensible, more development and validation is needed before a general extended bandwidth channel model can be recommended. For very wide bandwidth simulations this extended approach may not be tenable because the channel conditions may vary within the transmission bandwidth.

ANNEX 2

Comparative testing of HF modems

1 Introduction

The generality of the simulator architecture described in Annex 1 allows the simulation of an extremely wide range of HF ionospheric channel conditions. This can be problematic when a general comparison between different HF modems is required. This Annex describes a technique that employs a simplified HF channel simulation to provide a comprehensive performance characterization of HF modems in a graphical form.

2 Modem characterization technique

The characterization technique utilizes a simulation of two independently fading HF skywave modes. Magneto-ionic splitting is neglected – i.e. only one term from equations (1) and (2) in Annex 1 is employed. Both modes have equal mean attenuation, equal Doppler shifts and spreads, and are separated by a multipath delay. The *S*/*N* is set by adding band limited Gaussian noise.

Whilst Doppler shift is held fixed (usually zero), the performance of a modem is measured in accordance with a common set of test criteria, such as that specified in Table 1. BER is used as the measure of modem performance. At each Doppler spread/multipath delay combination the *S*/*N* which produces a BER within the acceptable range is determined (the length of each test should be determined by the same algorithm as presented in Annex 3, § 6; such test lengths have proved to be satisfactory in practice). The resultant data can be presented as a three-dimensional plot, whereby *S*/*N* (up to a high maximum allowed value), Doppler spread and multipath delay are attributed to the three orthogonal axes. Within the three dimensional space, the locus of points of constant BER describes a surface which indicates the modem performance across the range of tested channel conditions.

TABLE 1

Suggested criteria for comparative modem tests

Input parameter	Range	Increment
Multipath differential time delay (ms)	0-4 4-12 12-20	0.5 1.0 2.0
Doppler spread (Hz)	0.1 0.5-4.0 4-20 20-40	Not applicable 0.5 2 4
S/*N* (dB)	–10 to 50	1
Acceptable BER range[(1)]	2×10^{-3} to 0.5×10^{-3}	

(1) The BER range may be varied to suit the requirements of the user's application.

NOTE 1 – The length of individual tests should be set in accordance with Annex 3, § 6.

In general, the modem performance surfaces produced by this technique have a low level, relatively flat working region, in which the modem achieves the required BER performance. This valley region is bounded by steeply rising sides that rapidly climb to the maximum *S*/*N* used in the simulations, producing a plateau region in which the modem fails to reach the performance criteria. Indeed, the plateau region generally indicates that the Doppler and multipath spreads are so severe that increasing the *S*/*N* will not improve performance.

Figures 4 to 6 show a series of example performance surfaces for a particular 8-PSK serial tone modem operating at user data rates of 2 400, 1 200, and 300 bit/s. The plots show that the modem can provide stable performance over a range of Doppler and multipath conditions, but that once certain limits are reached (e.g. about 4 Hz and at about 10 ms for the 2 400 bit/s data rate) the modems' performance is rapidly degraded. The expansion, and drop, in the valley floor as the data rate is decreased is a clear example of how the performance of HF modems may be compared using this technique. When reporting results of modem testing it is important to quote all necessary modem settings, as data rate, FEC and interleaving can have a significant effect on BER.

FIGURE 4

Example performance surface for a 2 400 bit/s 8-PSK serial tone modem

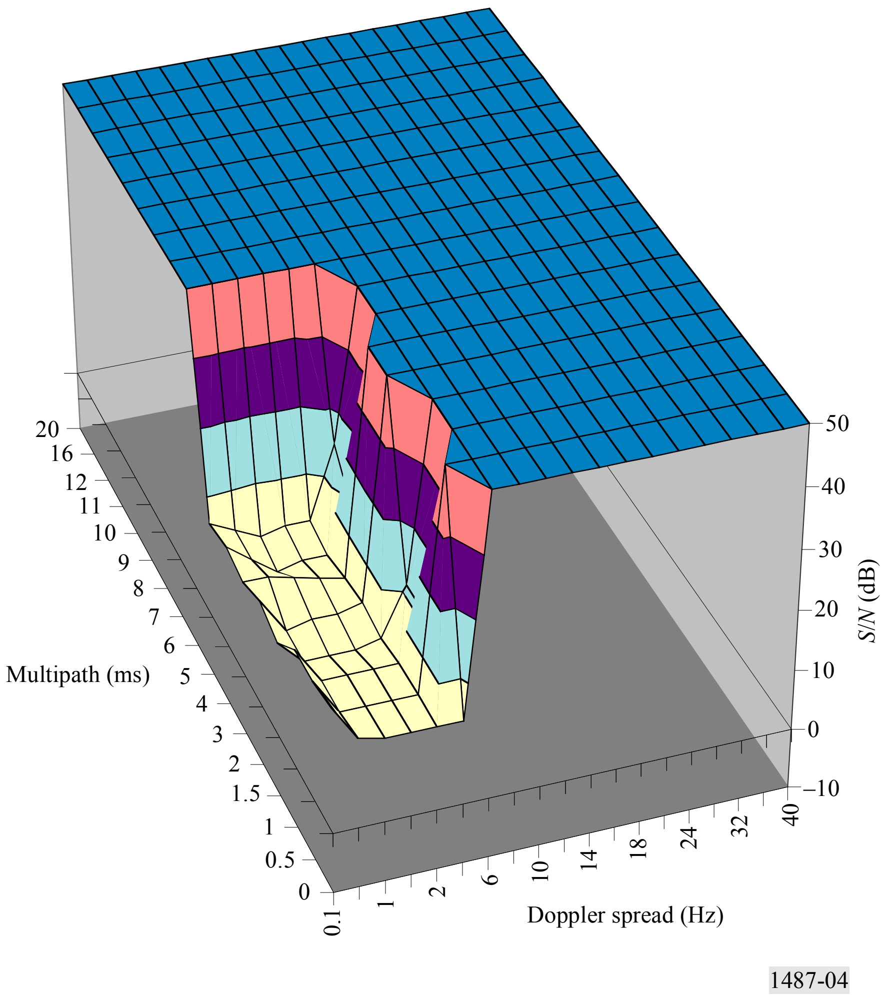


FIGURE 5

Example performance surface for a 1 200 bit/s
8-PSK serial tone modem

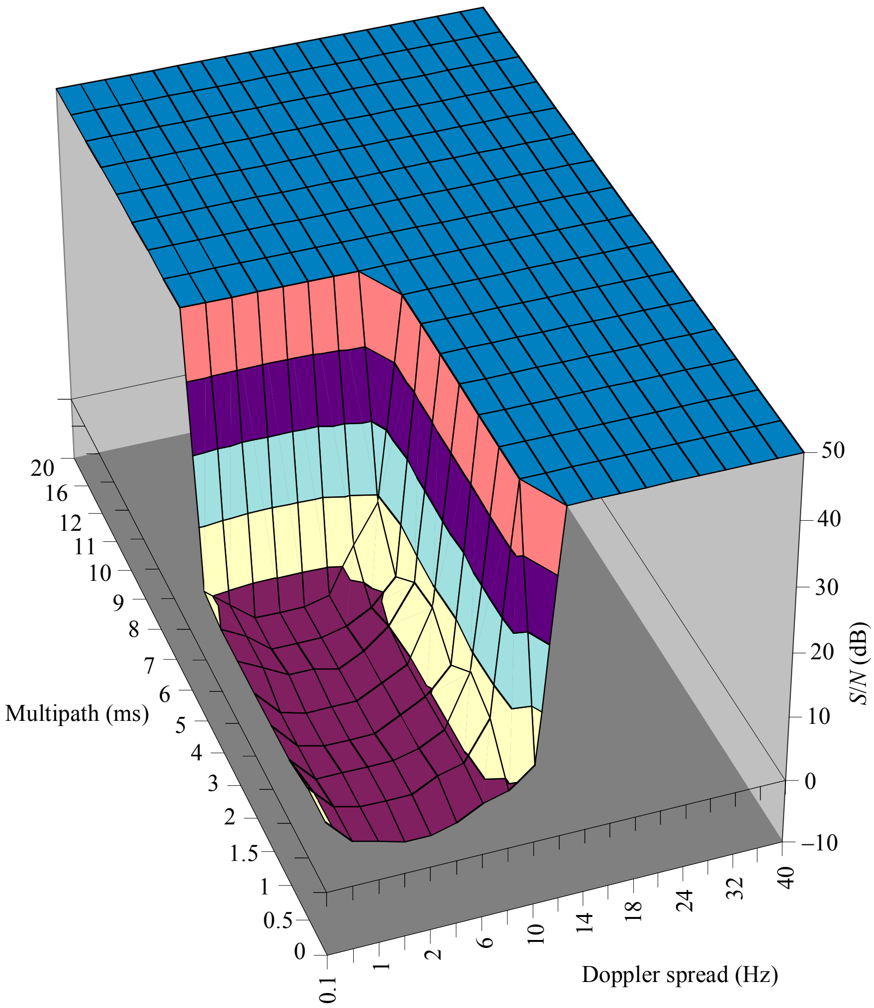


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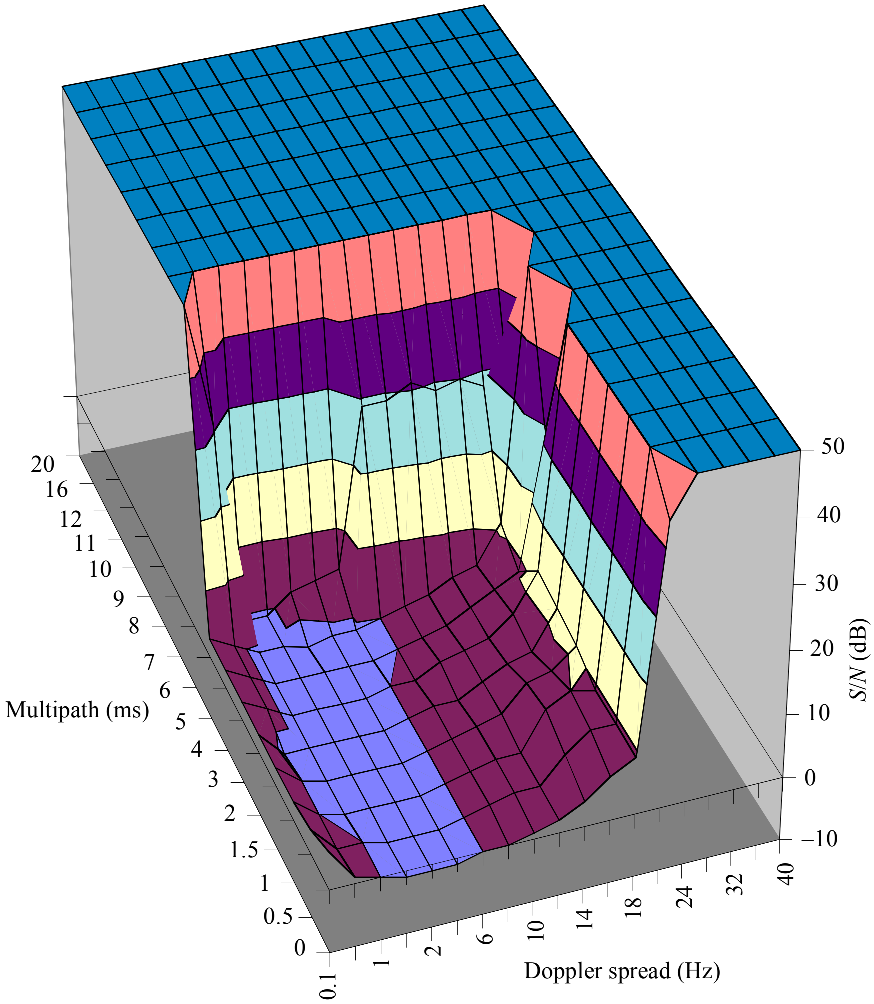
FIGURE 6

Example performance surface for a 300 bit/s 8-PSK serial tone modem



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ANNEX 3

Quantitative testing of HF modems

1 Representative channel parameter combinations

Modem performance can be specified as the BER as a function of *S*/*N* for two independently fading paths with equal mean attenuation, equal frequency spreads and no frequency shifts. The differential time delay in the following sections is defined as the multipath delay between the two modes, while the frequency spread is the 2σ value as used in equation (2) of Annex 1.

When these representative parameter values are used for comparative testing it is recommended that the parameter values used should be quoted. For further information concerning latitude regions refer to the ITU-R Handbook on The ionosphere and its effects on radiowave propagation (1998).

2 Low latitudes

2.1 Quiet conditions

Differential time delay: 0.5 ms

Frequency spread: 0.5 Hz

2.2 **Moderate conditions** (see Note 1)

Differential time delay: 2 ms

Frequency spread: 1.5 Hz

NOTE 1 – These values correspond to the values for a poor channel as defined in the former Recommendation ITU-R F.520.

2.3 Disturbed conditions

Differential time delay: 6 ms

Frequency spread: 10 Hz

3 Mid-latitudes

3.1 **Quiet conditions** (see Note 1)

Differential time delay: 0.5 ms

Frequency spread: 0.1 Hz

NOTE 1 – These values correspond to the values for a good channel as defined in the former Recommendation ITU-R F.520.

3.2 **Moderate conditions** (see Note 1)

Differential time delay: 1 ms

Frequency spread: 0.5 Hz

NOTE 1 – These values correspond to the values for a moderate channel as defined in the former Recommendation ITU-R F.520.

3.3 **Disturbed conditions** (see Note 1 of § 2.2)

Differential time delay: 2 ms

Frequency spread: 1 Hz

3.4 Disturbed near vertical incidence (ground wave component should be added if required)

Differential time delay: 7 ms

Frequency spread: 1 Hz

4 High latitudes

4.1 **Quiet conditions** (see Note 1 of § 3.2)

Differential time delay: 1 ms

Frequency spread: 0.5 Hz

4.2 Moderate conditions

Differential time delay: 3 ms

Frequency spread: 10 Hz

4.3 Disturbed conditions

Differential time delay: 7 ms

Frequency spread: 30 Hz

5 Occurrence statistics

As an indication of the probability of occurrence of disturbed conditions, the statistics given below may be noted.

5.1 Low latitudes

Differential time delays of 4 ms will be exceeded approximately 5% of the time.

Doppler spreads of 3 Hz will be exceeded approximately 5% of the time.

5.2 High latitudes

Differential time delays of 5 ms will be exceeded approximately 5% of the time.

Doppler spreads of 25 Hz will be exceeded approximately 5% of the time.

6 Length of test

The length of test required is dependent upon the Doppler spread, the user data rate, and the level of BER that is to be measured. It is recommended that tests should last for the longer of either 3 000 times the reciprocal of the Doppler spread or 100 times the reciprocal of the product of the BER and the data rate. Some examples are presented in the Table 2.

TABLE 2

Examples of test length

Doppler spread (Hz)	3 000/Doppler spread (s)	BER	Data rate (bit/s)	100/(BER × data rate) (s)	Selected test length (s)
0.5	6 000	1×10^{-3}	600	167	6 000
2	1 500	1×10^{-3}	600	167	1 500
5	600	1×10^{-3}	600	167	600
10	300	1×10^{-3}	600	167	300
20	150	1×10^{-3}	600	167	167