

SECTION 6F: IONOSPHERIC PROPAGATION PREDICTION AND APPLICATIONS AT FREQUENCIES ABOVE ABOUT 30 MHz

RECOMMENDATION ITU-R P.531-3

IONOSPHERIC EFFECTS INFLUENCING RADIO SYSTEMS INVOLVING SPACECRAFT

(Question ITU-R 218/3)

(1978-1990-1992-1994)

The ITU Radiocommunication Assembly,

considering

a) that ionospheric effects may influence the design and performance of ISDN (Integrated Services Digital Network) and other radio systems involving spacecraft,

recommends

1. that the information contained in Annex 1 should be used as required in the planning and design of such systems.

ANNEX 1

Ionospheric effects upon Earth-space propagation

1. Ionospheric effects

A signal carrier which penetrates the ionosphere is modified by the medium due to the presence of electrons and the Earth's magnetic field. Both large-scale changes due to the variation of electron density, as well as smaller scale irregularities, affect the carrier. The effects include scintillation, absorption, variation in the direction of arrival, propagation delay, dispersion, frequency change and polarization rotation. These effects on transmission, at frequencies mainly above about 20 MHz, are treated in this Annex.

2. Scintillation**2.1 Introduction**

Scintillations, as discussed in this Annex, are variations of amplitude, phase, polarization and angle-of-arrival produced when radio waves pass through electron density irregularities in the ionosphere. Ionospheric scintillations present themselves as fast fluctuations of signal level with peak-to-peak amplitude fluctuations from 1 dB to over 10 dB and lasting for several minutes to several hours. The phenomena are caused by one of two types of ionospheric irregularities:

- sufficiently high electron density fluctuations at scale sizes comparable to the Fresnel zone dimension of the propagation path, or
- sharp gradients of ambient electron density, especially in the direction transverse to the direction of propagation.

Either type of irregularity is known to occur in the ionosphere under certain solar, geomagnetic and upper atmospheric conditions, and the scintillations can become so severe that they represent a practical limitation for communication systems. Scintillations have been observed at frequencies from about 10 MHz to about 12 GHz.

For systems applications, scintillations can be characterized by the fading depth and period. A useful index to quantify the severity of scintillation is the scintillation index, S_4 , which is defined as the standard deviation of received power divided by the mean value of the received power, i.e.,

$$S_4^2 = \frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2} \quad (1)$$

where I is the carrier intensity, and $\langle \rangle$ denotes ensemble average.

The fading period of scintillation varies over quite a large range from less than one tenth of 1 s to several minutes, as the fading period depends both upon the apparent motion of the irregularities relative to the ray path, and in the case of strong scintillation, on its severity. The fading period of gigahertz scintillation ranges from approximately 1 to 10 s. Long period (of the order of tens of seconds) components of saturated scintillation (S_4 approaches 1) at VHF and UHF bands have also been observed.

2.2 *Modelling/scaling rules for system applications*

Ionospheric scintillations exhibit a wide range of variations in frequency dependence, morphology patterns, and diurnal, seasonal and solar cycle dependence. Different signal statistics have been found in different observations. An enormous amount of literature is available and new findings based on refined measurement techniques and modelling methodology appear each year. System engineers are advised to use reliable/relevant published data for applications. If direct data and/or findings are not available or applicable, the modelling/scaling rules in the following sections should be used.

2.3 *Frequency dependence of scintillation*

If results from direct measurement are not available, an $f^{-1.5}$ frequency dependence of S_4 is recommended for engineering applications.

2.4 *Instantaneous statistics and spectrum behaviour*

2.4.1 *Instantaneous statistics*

During an ionospheric scintillation event, the Nakagami density function is believed to be adequately close for describing the statistics of the instantaneous variation of amplitude. The density function for the intensity of the signal is given by:

$$p(I) = \frac{m^m}{\Gamma(m)} I^{m-1} \exp(-mI) \quad (2)$$

where the Nakagami “ m -coefficient” is related to the scintillation index, S_4 by:

$$m = 1 / S_4^2 \quad (3)$$

In formulating equation (2) the average intensity level of I is normalized to be 1.0. The calculation of the fraction of time that the signal is above or below a given threshold is greatly facilitated by the fact that the distribution function corresponding to the Nakagami density has a closed form expression which is given by:

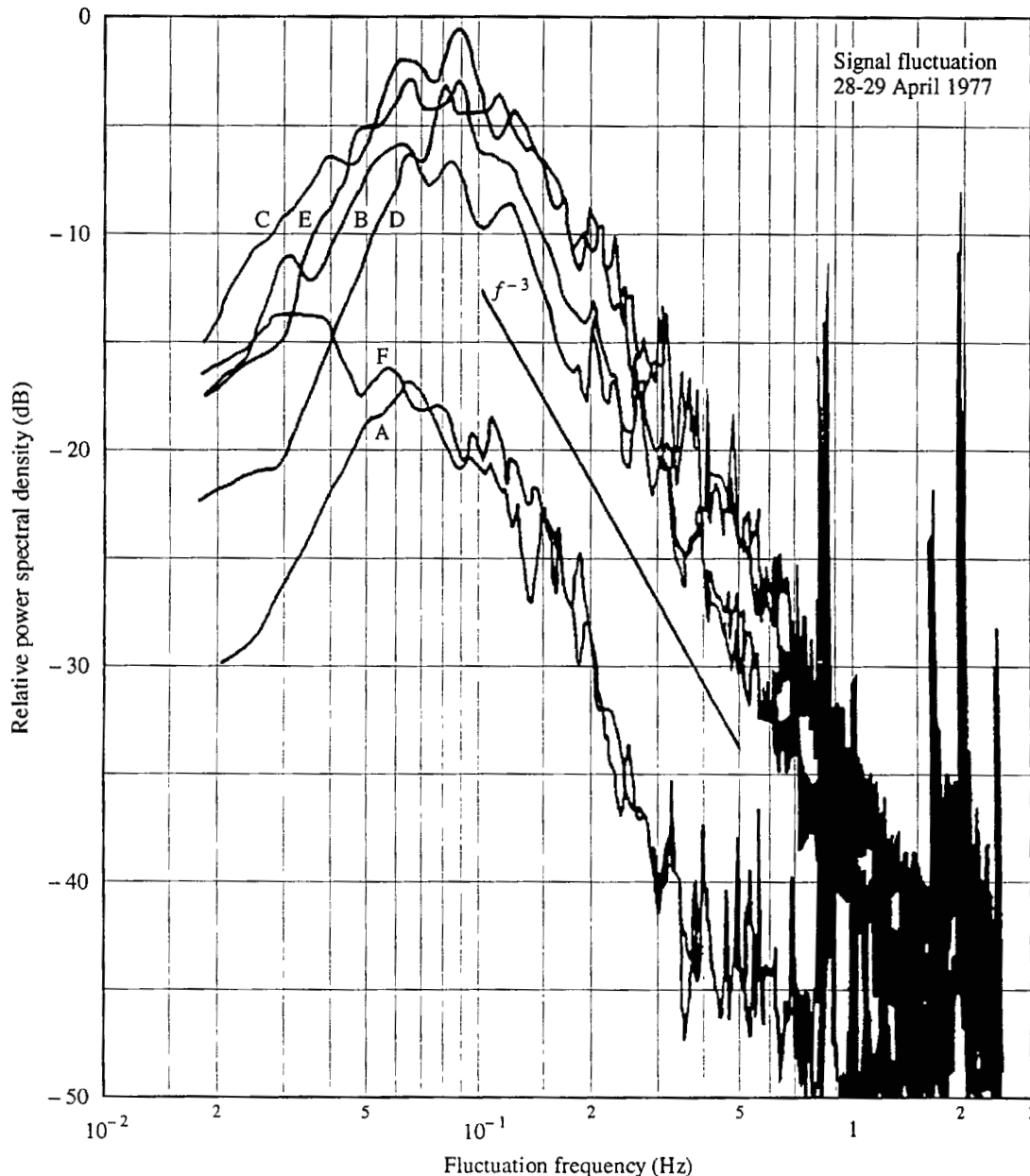
$$P(I) = \int_0^I p(x) dx = \frac{\Gamma(m, mI)}{\Gamma(m)} \quad (4)$$

where $\Gamma(m, mI)$ and $\Gamma(m)$ are the incomplete gamma function and gamma function, respectively. Using equation (4), it is possible to compute the fraction of time that the signal is above or below a given threshold during an ionospheric event. For example, the fraction of time that the signal is more than X dB below the mean is given by $P(10^{-X/10})$ and the fraction of time that the signal is more than X dB above the mean is given by $1 - P(10^{-X/10})$.

2.4.2 Spectrum behaviour

Since ionospheric scintillations are believed to be caused by relatively stationary refractive-index irregularities moving horizontally past the radio wave path, the spatial and temporal power spectra are related by the drift velocity. The actual relationship depends on the irregularity composition (power spectra) and a number of other physical factors. As a result, the power spectra exhibit a wide range of slopes, from f^{-1} to f^{-6} as have been reported from different observations. A typical spectrum behaviour is shown in Fig. 1. The f^{-3} slope as shown is recommended for system applications if direct measurement results are not available.

FIGURE 1
Power spectral density estimates for a geostationary satellite
(Intelsat-IV) at 4 GHz



The scintillation event was observed during the evenings
of 28-29 April 1977 at Taipei earth station

- A: 30 min before event onset
- B: at the beginning
- C: 1 h after
- D: 2 h after
- E: 3 h after
- F: 4 h after

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2.5 *Geometric consideration*

2.5.1 *Zenith angle dependence*

In most models, S_4^2 is shown to be proportional to the secant of the zenith angle, i , of the propagation path. This relationship is believed to be valid up to $i \approx 70^\circ$. At greater zenith angles, a dependence ranging between 1/2 and first power of $\sec i$ should be used.

2.5.2 *Seasonal-longitudinal dependence*

The occurrence of scintillations and magnitude of S_4 have a longitudinal as well as seasonal dependence that can be parameterized by the angle, β , shown in Fig. 2. It is the angle between the sunset terminator and local magnetic meridian at the apex of the field line passing through the line-of-sight at the height of the irregularity slab. The weighting function for seasonal-longitudinal dependence is given by:

$$S_4 \propto \exp \left[-\frac{\beta}{W} \right] \quad (5)$$

where W is a weighting constant depending on location as well as calendar day of the year. As an example, using the data available from Tangua, Hong Kong and Kwajalein, the numerical value of the weighting constant can be modelled as shown in Fig. 3.

2.6 *Morphology*

Scintillation can be categorized according to geomagnetic latitude, longitude, and local time. The latitudinal categorization consists of:

- equatorial scintillations, which are caused by plasma bubbles in the equatorial anomaly regions;
- mid-latitude scintillations, which are correlated with the occurrence of ionospheric spread-F;
- high-latitude scintillations with effects that differ between the auroral and polar regions, though both are closely related to auroral activity and geomagnetic activities.

A general sketch is provided in Fig. 4 and a summary of scintillation characteristics is given in Table 1.

Observations with the GPS satellites at frequencies 1.2 and 1.6 GHz showed that in and near the auroral oval, the most severe scintillations occur from noon to 14 MLT (magnetic local time), and from 22 to midnight MLT. Even near solar maximum, the morning sector (03 to 09 MLT) is relatively free of scintillation activity. These can be seen on Fig. 5. This figure shows the average scintillation activity observed during six weeks in February and March 1991 (soon after the solar maximum) as a function of geomagnetic latitude and local geomagnetic time. The total electron content (TEC) was measured every 0.8 s, and the standard deviation computed from samples of 100 s is coded in grey-scale.

2.7 *Cumulative statistics*

In design of ISDN and other radio systems, communications engineers have concerns not only with the system degradation during an event such as those described in § 2.3, 2.4 and 2.5, but also with the long term cumulative occurrence statistics. For communications systems involving a geostationary satellite, which is the simplest radio system configuration, Figs. 6 and 7 are recommended for the assessment and scaling of occurrence statistics. The sunspot numbers (SSN) cited are the 6-month averaged sunspot numbers available from the NTIA/TTS of the United States of America.

2.8 *Simultaneous occurrence of ionospheric scintillation and rain fading*

Ionospheric scintillation and rain fading are two impairments of completely different physical origin. However, in equatorial regions at years of high sunspot number, the simultaneous occurrence of the two effects may have an annual percentage time that is significant to system design. The cumulative simultaneous occurrence time was about 0.06% annually as noted at 4 GHz at Djutiluhar earth station in Indonesia. This value is unacceptably high for ISDN types of applications.

FIGURE 2a
The intersection of the propagation path with a magnetic field line
at the F-region height

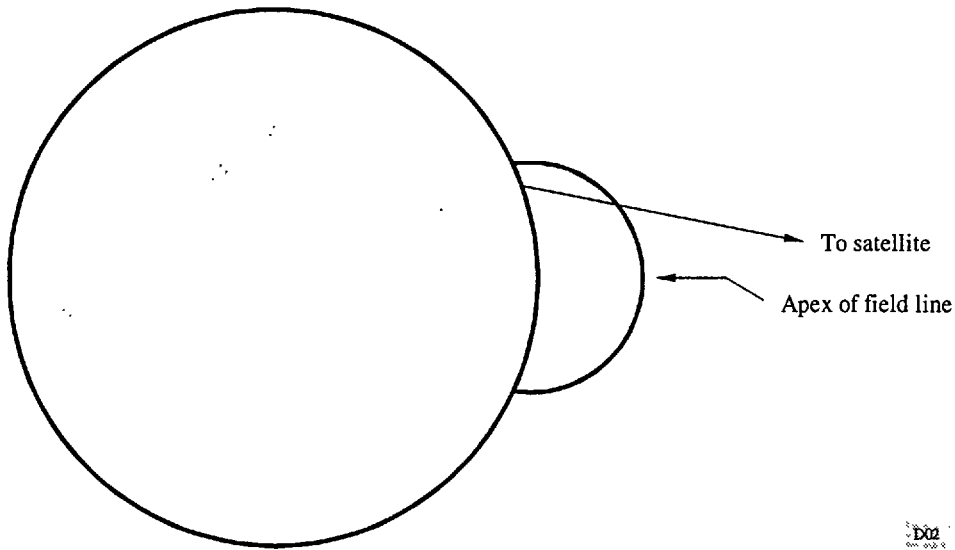
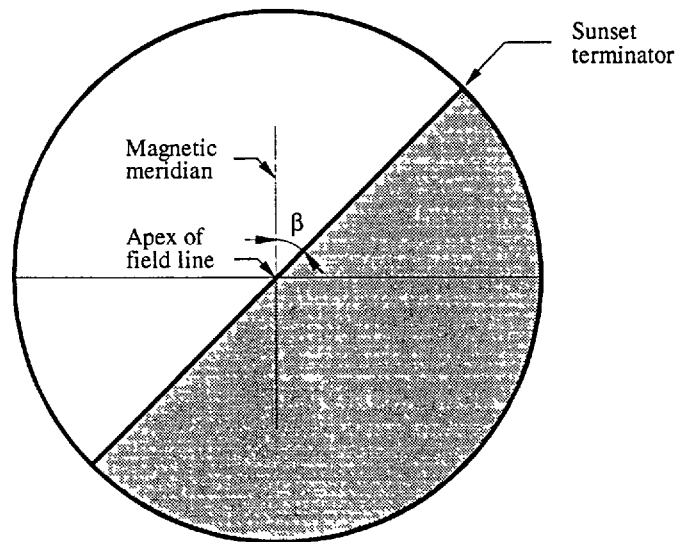


FIGURE 2b
The angle between the local magnetic meridian at the apex of the field line
shown in Fig. 2a and the sunset terminator



The simultaneous events have signatures that are often vastly different from those when only a single impairment, either scintillation or rain alone, is present. While ionospheric scintillation alone is not a depolarization phenomenon, and rain fading alone is not a signal fluctuation phenomenon, the simultaneous events produce a significant amount of signal fluctuations in the cross-polarization channel. Recognition of these simultaneous events is needed for applications to satellite-Earth radio systems which require high availability.