

CHAPTER 1 INTRODUCTION

The satellite communications industry is currently in the process of a "frequency evolution", moving from the frequency bands that have been in use for decades, C-Band, X-band, SHF, etc., to the higher allocated bands above 10 GHz. These new bands, designated as Ku band (12-18 GHz), Ka band (27-40 GHz), and EHF (3(1-300 GHz), offer wider bandwidths, higher data rates, and smaller component sizes, as well as vastly improved anti-jam performance for secure communications applications.

The advantages of these bands can be offset very quickly however, by the realities of increased propagation problems as the frequency of operation is increased. Attenuation caused by rain in the path can be a serious problem, and careful design and adequate "rain margins" are essential for successful system performance.

There are other propagation mechanisms affecting Earth-space communications performance that are also of concern to the systems designer and planner. These include gaseous attenuation; cloud and fog attenuation; rain and ice depolarization; amplitude phase, and angle-of-arrival scintillation; and sky noise.

The purpose of this Handbook is to provide, in one complete reference source, the latest information on critical propagation effects and how they impact communications system design and performance. NASA, who has supported a large part of the experiments] work in radiowave propagation on space communications links, recognized the need for a reference handbook of this type,

and initiated a **program** in the **late 1970's** to develop and update a document which will **meet this** need. This present publication is **the fourth edition** of the NASA Handbook **which** focuses **on** propagation effects from **10 to 100 GHz**. A companion handbook (Flock-1987) covers propagation effects on satellite systems at frequencies below **10 GHz**.

1.1 OVERVIEW OF **THIS** BOOK

The NASA Propagation Effects Handbook for Satellite Systems Design provides a concise summary of the major propagation effects experienced **on** earth-space paths in the **10 to 100 GHz** frequency range. **The** dominant effect--attenuation due to rain--is **dealt** with **in** some detail, in terms of both experimental data from measurements **and** the mathematical. and conceptual models devised to explain and predict the data.

Other effects such as clear air attenuation and depolarization are also presented. The estimation of depolarization due **to** rain and **ice** has not been developed to the degree required for **preparing** good design estimates for satellite systems. Therefore, a comprehensive chapter **on** depolarization has been included that attempts to consolidate the work of several investigators in this area.

The Handbook has **been** arranged in two parts. Chapters **II** through **V** comprise the descriptive part. They deal **in** some **detail** with rain systems, rain and attenuation models, depolarization, and experimental data. This descriptive part of the Handbook is intended to provide background for system engineers and planners who want more detail than that presented in the later design chapters.

Chapters **VI** and **VII** make up the design part of the Handbook and may be used almost independently of the earlier chapters. In Chapter **VI**, the **design** techniques recommended for **predicting** propagation effects **in** earth-space communications systems are . presented. Some selection has been made from alternative **models** in

order that **only** one design technique be utilized. This selection was made based on the ability of the technique to **model** the experimental results. The chapter includes step-by-step procedures for using the prediction models and numerous examples.

Chapter **VII** addresses the questions of where in the system design process the effects of propagation should be considered, and what precautions should be taken when applying the propagation results. The unadvised use of propagation results in the link margin can result in overdesign. This chapter bridges the gap between the propagation research data and the classical link budget analysis of earth-space communications system. This chapter presents generalized design procedures, and illustrates their use through extensive examples.

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The troposphere, and the hydrometers (rain, snow, cloud droplets, etc.) it contains, can impair satellite communication links using the bands above 10 **GHz** in four ways:

Amplitude Reduction

The amplitude of the received signal is reduced from the "**free-space**" value through absorption and/or scattering by oxygen, water vapor, rain drops, and cloud and fog droplets. Of these, oxygen absorption in the 55-65 GHz band has the largest effect. Attenuation in this band is so great as to make **Earth-space** communication (at least from the surface) virtually impossible. At frequencies below the oxygen absorption band, water vapor becomes the most prominent attenuating gas. **It** causes a weak absorption peak (generally less than **1 dB** on a vertical path, depending on humidity) in a band around 22 GHz. Both gases also cause appreciable attenuation above the oxygen band. Aside from oxygen absorption around 60 GHz, the greatest attenuation effect comes from rainfall. Because of its severity and unpredictability, rain attenuation rightly receives the most attention in the satellite system design

process for frequencies above 10 GHz. (Accordingly, it **also** receives the most attention in this Handbook.) Attenuation due to clouds is relatively minor compared to that of rain, but it is normally present for a much larger percentage of the time. It should be considered in systems operating above about 30 GHz, in locations where heavy rain is rare but cloudiness is common. Fog attenuation **is** not normally of concern in satellite systems because fog layers are relatively thin and do not usually occupy very much of the propagation path.

Thermal Noise Increase

Elementary physics tells us that anything that absorbs electromagnetic energy radiates it as well. The energy radiated by the tropospheric absorbing media (oxygen, water vapor, rain drops, etc.) **is** incoherent and broadband. It is received by the Earth station antenna along with the downlink signal, and appears at the receiver output as thermal noise - indistinguishable from the thermal noise generated in the receiver front end. The effect of the received noise energy is accounted for by adding a "sky noise" temperature to the Earth station receiver noise temperature. This sky noise temperature turns out to be related to the attenuation that the absorbing medium produces. Disregarding extraterrestrial sources such as the sun, sky noise temperature is zero when the attenuation **is** zero, and it asymptotically approaches the physical temperature of the medium as the attenuation becomes large. The effect of the thermal noise increase on system performance is to reduce the downlink carrier-to-noise ratio, which has exactly the same effect as an amplitude reduction on the downlink. However, because the thermal noise increase is additive, the magnitude of the effect depends greatly on the Earth station noise temperature in the absence of sky noise. For example, a **100°K** sky noise contribution (corresponding to about 2 **dB** of rain attenuation) would produce a signal-to-noise ratio degradation of 3 **dB** **if** the system noise temperature was **100°K without** rain, but the same sky noise

contribution would be negligible if the Earth station noise temperature started out at **1000°K**.

Interference Increase

Systems that employ orthogonal polarizations to reuse the spectrum are subject to self-interference through crosstalk between the oppositely-polarized channels. The degree of self-interference is established by satellite and Earth station antenna **performance**, and by the depolarizing effects of rain drops and ice crystals in the path. Rain depolarization increases with rain rate and frequency and is well-correlated with rain attenuation. Depolarization from high-altitude ice clouds is normally associated with thunderstorms but can occur in the absence of rain attenuation: The effect of depolarization on the communication channel depends on the type of modulation used. For example, a given degree of depolarization will produce a greater increase in bit error rate on a digital link using QPSK than it would with BPSK. The effect of depolarization interference is fundamentally different from the amplitude reduction or noise increase propagation effects in that increasing the link power does not reduce the interference. This is because a power increase raises the level of the desired and the interfering signals simultaneously. Crosspolarization can be reduced, however, by employing a special adaptive rotation network on the antenna feed. Another type of interference that can be made worse by propagation effects is intersystem interference. Rain can cause scattering of electromagnetic energy out of the line-of-sight, resulting in increased leakage of uplink power into the receive beam of an adjacent satellite, or between terrestrial line-of-site systems and low-angle Earth station antennas.

Signal Modulation

Earth stations operating at low elevation angles are subject to scintillation caused by tropospheric turbulence. This consists of fast random fluctuations in the amplitude and phase of the signal. The effects of scintillations on the channel depend on the type of

modulation used and the receiver AGC performance. The power spectrum of the fluctuation falls off quickly with increasing frequency, so the effects should be expected to be primarily brief signal drop-outs or losses of synchronization, rather than any actual modulation of the information-carrying waveforms.

Propagation impairments are dependent on the following:

Operating Frequency. With the exception of signal attenuation by gaseous absorption lines, the severity of tropospheric impairments increases with frequency.

Antenna Elevation Angle and Polarization. The length of the part of the propagation path passing through the troposphere varies inversely with elevation angle. Accordingly, propagation losses, noise, and depolarization also increase with decreasing elevation angle. Rain attenuation is slightly polarization-sensitive. Depolarization is also polarization-sensitive, with circular polarization being the most susceptible.

Earth Station Altitude. Because less of the troposphere is included in paths from higher altitude sites, impairments are less.

Earth Station Noise Temperature. This determines the relative contribution of sky noise temperature to system noise **temperature**, and thus the effect of sky noise on the **downlink** signal-to-noise ratio.

Local Meteorology. The amount and nature of the rainfall in the vicinity of the Earth station are the primary factors in determining the frequency and extent of most propagation impairments. **Rain-**caused impairments depend on the rate of rain fall, so how the rain tends to fall (thunderstorms versus steady showers) is as important as the cumulative amount of rainfall. The type and extent of cloud cover, and local humidity characteristics are other meteorological factors that determine the magnitude of propagation impairments.

Figure 1-1 shows them **magnitude** and variation of three significant tropospheric propagation effects: rain attenuation, sky noise due to rain, and rain depolarization. These are presented in

terms of their estimated exceedance statistics. The curves give the approximate percentage of an average year in which the magnitude of the effect exceeds the value given on the horizontal axis. The first plot gives rain attenuation for three frequencies: 14, 20 and 30 GHz. The second plot shows the signal-to-noise ratio degradation caused by rain attenuation and the accompanying sky noise increase. This is shown for 30 GHz, with three values of Earth station receiver noise temperature. The third plot is the **cross-polarization isolation (XPI)**, assuming that the antenna's axial ratio is 0.4 dB. XPI is the ratio of the power received in one of the polarization channels to the "cross talk" power from the oppositely-polarized channel. The plot also gives, for two digital modulation schemes, the reduction in signal to noise density ratio that would have an effect on bit error rate equivalent to that of the cross-polarized interference.

The predictions shown in Figure 1-1 were derived using the procedures presented in this Handbook. The rain attenuation statistics were computed using the Global Model, following the steps outlined in Section 6.3.2. The thermal noise increase due to rain was computed using the formula given in Section 6.7.4. The depolarization curve was based on what is known in this Handbook as the "**CCIR** Approximation," which is presented in Sections 4.3.2 and 6.6.2. The correspondence between depolarization and equivalent degradation for BPSK and QPSK uses the results of Prabhu (1969).

This brief overview has been intended to introduce the system designer to the range of tropospheric effects to be expected on earth-space links operating at frequencies above 10 GHz so that he or she may more effectively use this Handbook. Other references relating to the general area of radiowave propagation effects include (**Ippolito**, 1981) (**Ippolito**, 1986), the IEEE Proceedings on Antennas and Propagation, and Radio Science. An excellent bibliography is also available (Dutton and Steele - 1982) for those seeking further general (or specific) literature.

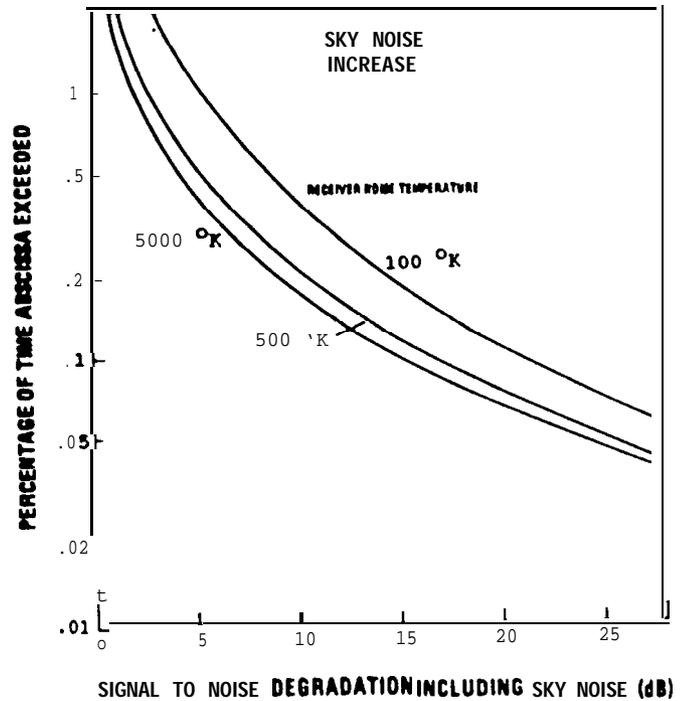
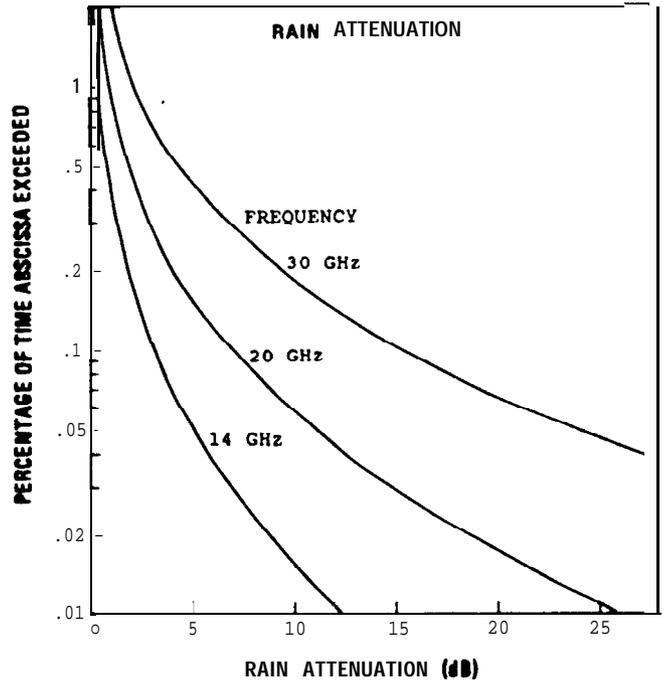
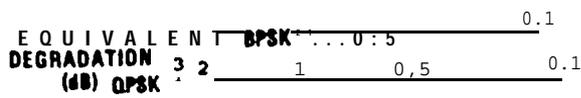
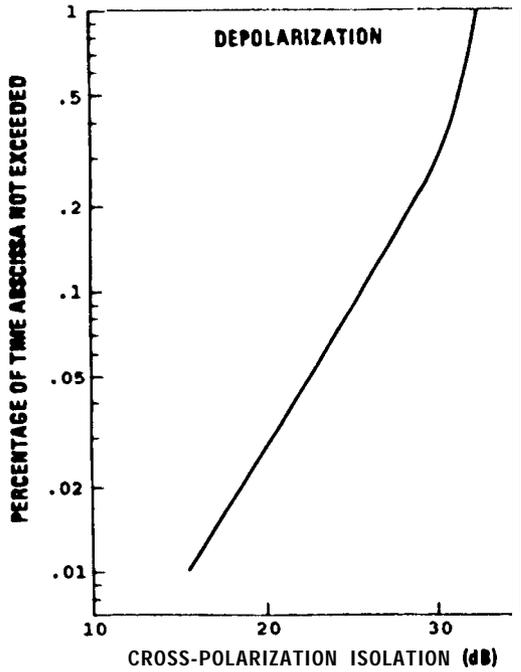


Figure 1-1. Predicted Propagation Impairments for Washington, D.C., at sea level, Elevation Angle = 45.4°

1.3 References

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