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Propagation Effects Handbook for Satellite Systems Design

Louis J. Ippolito

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Propagation Effects Handbook for Satellite Systems Design

Dr. Louis J. Ippolito
ITT Industries
Advanced Engineering & Sciences
45145 Research Place
Ashburn, VA 20147
Phone: (703) 858-4061, Fax: (703) 858-4130
E-mail: louis.ippolito@itt.com

Abstract

This paper describes the latest edition of the NASA Propagation Effects Handbook for Satellite Systems Design and presents a summary of application of the handbook information to satellite link design and performance. NASA, which has supported a large part of the experimental 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 that will meet this need. The Fifth Edition provides, in a single document, an update to two previous NASA handbooks; the fourth edition of a handbook which focused on propagation effects from 10 to 100 GHz (Ippolito, 1989), and the second edition of a companion handbook which covered propagation effects on satellite systems at frequencies below 10 GHz (Flock, 1987). This Fifth Edition covers the full range of radiowave frequencies that are in use or allocated for space communications and services, from nominally 100 MHz up to 100 GHz.

Introduction

The Fifth Edition of the Propagation Effects Handbook for Satellite Systems Design provides, in one complete reference source, the latest information on atmospheric propagation effects and how they impact satellite communications system design and performance. The National Aeronautics and Space Administration, NASA, which has supported a large part of the experimental 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 that will meet this need. This Fifth Edition provides, in a single document, an update to two previous NASA handbooks; the fourth edition of a handbook which focused on propagation effects from 10 to 100 GHz (Ippolito, 1989), and the second edition of a companion handbook which covered propagation effects on satellite systems at frequencies below 10 GHz (Flock, 1987). This Fifth Edition covers the full range of radiowave frequencies that are in use or allocated for space communications and services, from nominally 100 MHz up to 100 GHz.

The basic intention of the Fifth Edition is to combine the scope of the previous handbooks into a single document, with elimination of duplication as much as possible. This Fifth Edition has a completely new outline, different from either of the two previous handbooks. The intent is to provide a more cohesive structure for the reader. The handbook incorporates a unique, new concept with several levels of “entrance” into the handbook.

Several major developments in satellite communications and the study of propagation effects have occurred since publication of the prior NASA handbooks. New propagation measurement campaigns have been completed or are in progress, providing new data for the evaluation of link degradations on satellite links. New propagation models and prediction techniques are available, covering the traditional propagation effects along with several new areas. New satellite applications have been thrust into the forefront of the satellite communications industry, requiring new approaches for the evaluation of propagation effects. The proliferation of new and competing applications in the frequency bands allocated to space communications has increased the importance and priority of understanding spectrum sharing and interference mitigation. Propagation conditions are a critical component of a viable sharing and interference process.

Handbook Structure

The Propagation Effects Handbook for Satellite Systems Design, Fifth Edition, is divided into three sections. Section 1 provides the background, historical development, theory, and basic concepts of the propagation effects of concern to the satellite systems engineer. The prediction techniques developed to address the critical propagation effects are presented in Section 2. Information on how to apply the prediction methods for specific satellite systems applications is provided in Section 3. (see figure 1 below)

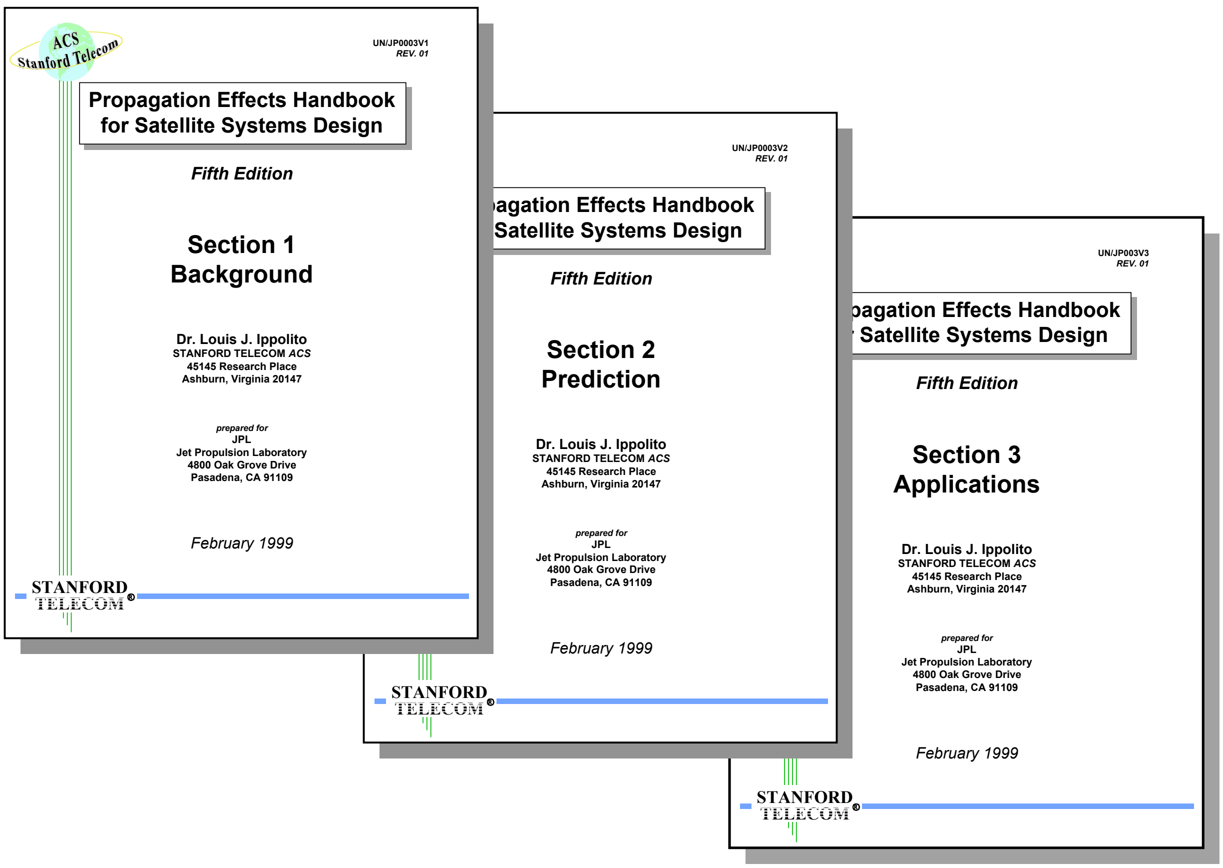

Figure 1 Fifth Edition of the Propagation Effects Handbook for Satellite Systems Design (Revision 1, released Feb. 1999)

Section 1 begins with an overview of propagation effects on satellite communications. The propagation effects are then introduced and background theory and developments are described. The frequency dependence of radiowave propagation is recognized, and the effects are divided into two groups; ionospheric effects, influencing systems operating at frequencies below about 3 GHz, and tropospheric effects, influencing systems operating at frequencies above about 3 GHz. Radio noise, which can affect satellite systems in all operating bands, is then described. The section concludes with a comprehensive description of propagation databases, including points of contact and electronic addresses.

Section 2 provides descriptions of prediction models and techniques for the evaluation of propagation degradation on satellite links. Step-by-step procedures are provided where available. The first two subsections present propagation effects for ionospheric effects and for tropospheric effects, respectively. The third subsection presents prediction methods for radio noise. The fourth subsection describes several general modeling procedures, including statistical considerations, frequency scaling and elevation angle scaling. The final subsection presents models for the restoration of links subject to propagation impairments, including site diversity, orbit diversity and adaptive FEC.

Section 3 provides roadmaps for the application of the prediction models given in Section 2 to specific satellite systems and applications. Suggested approaches to evaluating link propagation effects and their impact on system design and performance are provided. Section 3 includes evaluation of propagation effects and their impact on systems design and performance

Handbook Approach

The Fifth Edition of the Propagation Effects Handbook for Satellite Systems Design is intended for the systems engineer and link designer who is interested in the latest and most accurate methodology available for the evaluation of radiowave propagation effects on satellite communications. The handbook is structured with several levels of "entrance" into the handbook, as highlighted by Figure 2.

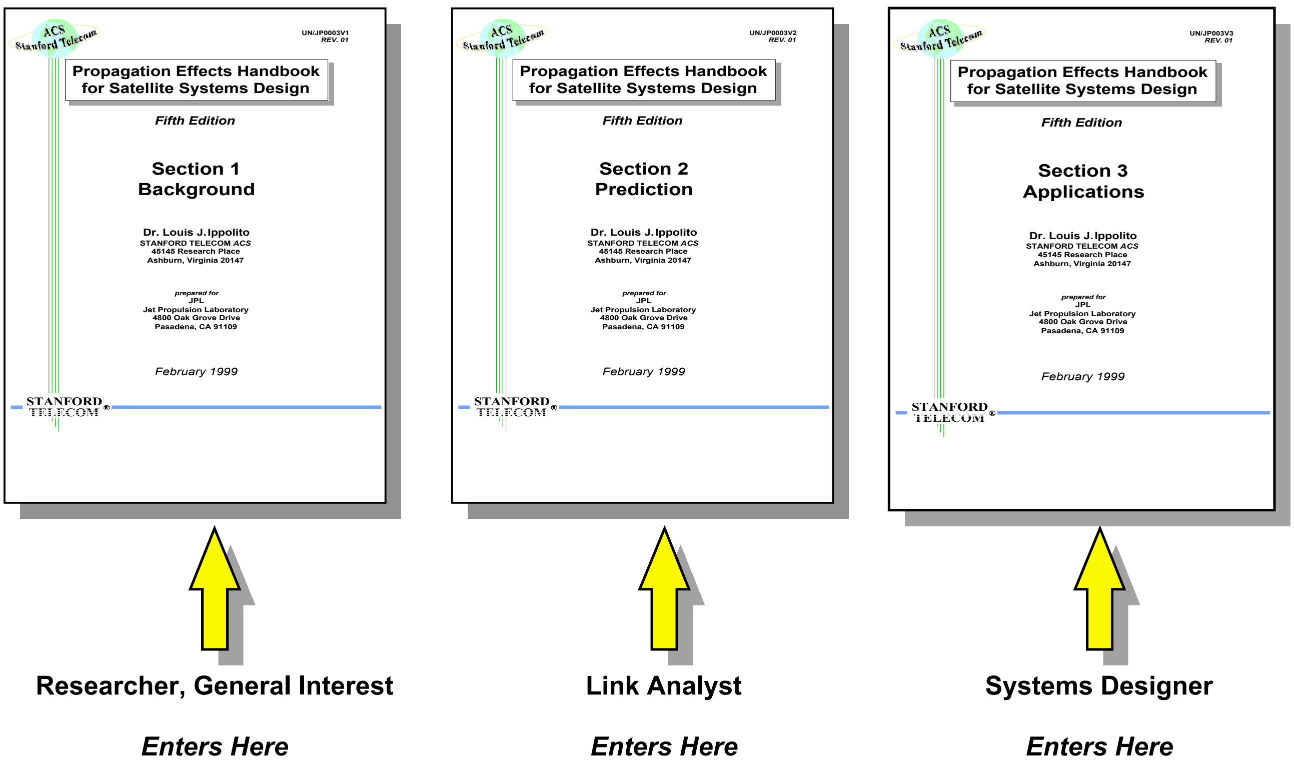

Figure 2 Three-section structure for the handbook

The general researcher or someone new to the subject who may not have a full awareness of the background and history of propagation effects and their impact on satellite communications could enter in Section 1, which provides an overview of propagation effects and the background theory involved in the prediction methodology. Section 1 also provides an extensive listing of resources for additional information and backup data important to the area of propagation effects and satellite communications.

The link analyst or engineer who is familiar with propagation and satellite communications issues and knows which propagation effects are of interest would enter into Section 2 where concise step-by-step procedures for each effect are available. Section 2 also includes general modeling procedures, including statistical considerations, frequency scaling and elevation angle scaling. Section 2, in addition, presents models for the restoration of links subject to propagation impairments, including site diversity, orbit diversity and adaptive FEC.

The system designer who has a good understanding of the system aspects of satellite communications but may not know just which propagation impairments are important to the particular system or application under consideration would enter through Section 3. Here the reader will find roadmaps for the application of the prediction models given in Section 2 to specific satellite systems and applications. Suggested approaches to evaluating link propagation effects and their impact on system design and performance are also provided in Section 3.

These entrance levels are only suggestions for the reader, to avoid unnecessary reading and to optimize the use of the handbook. Suggestions on ways to improve the document structure, or on specific additional information that would be useful to the reader to include in later editions of the handbook, are always welcome by the author.

Section 1 BACKGROUND

Section 1 begins with an overview of propagation effects on satellite communications. The propagation effects are then introduced and background theory and developments are described. The frequency dependence of radiowave propagation is recognized, and the effects are divided into two groups; ionospheric effects, influencing systems operating at frequencies below about 3 GHz, and tropospheric effects, influencing systems operating at frequencies above about 3 GHz. Radio noise, which can affect satellite systems in all operating bands, is then described. The section concludes with a comprehensive description of propagation databases, including points of contact and electronic addresses.

Section	Topic
1.0	Introduction to Section 1
1.1	Overview: Propagation Effects on Satellite Communications
1.2	Ionospheric Effects
1.3	Tropospheric Effects
1.4	Radio Noise
1.5	Propagation Data Bases
1.6	References – Section 1

Table 1. Contents of Section 1 INTRODUCTION

The principal topics and associated subsection numbers for Section 1 are listed in Table 1.

Section 2 PREDICTION

Section 2 provides descriptions of prediction models and techniques for the evaluation of propagation degradation on satellite links. Step-by-step procedures are provided where available. Section 1 provides the background, historical development, theory, and basic concepts of the propagation effects of concern to the satellite systems engineer. The section includes theory and basic concepts, propagation measurements, and available databases. Information on how to apply the prediction methods for specific satellite systems applications is provided in Section 3.

The development of reliable propagation effects prediction models requires measured data to validate the predictions. New propagation measurements in several frequency bands have been accomplished since the last handbook publication. Table 2 lists some of the satellites which had beacons on board specifically intended for the evaluation of propagation effects. Propagation data has also been developed from other sources including terrestrial links, tracking beacons, and from direct measurement of information bearing signals. For example, land mobile propagation data in the 1.5 GHz region was obtained in the Eastern U.S. from MARECS-B2 and in Australia from ETS-V and INMARSAT.

Satellite	Organization	Launch Date	Frequency (GHz)	Polarization	Measurement Region(s)

Olympus	ESA	1989	12.5 19.7 29.7	LP Dual Switched LP @933 Hz LP	Europe And Eastern U.S.
Italsat F1	Italy	1991	18.685 39.592 49.49	Dual LP CP with ± 500 MHz sidebands Dual switched LP @ 933 Hz	Europe
ACTS	NASA	1993	20.185 27.5	LP LP	CONUS Alaska Canada

Table 2. Recent Satellites Providing Propagation Measurements

Propagation research since publication of the last handbooks has resulted in the development and publication of propagation prediction models in several new areas. These include:

- Tropospheric Scintillation
- Cloud Attenuation and Scintillation
- Ice Depolarization
- Wet Surface Effects
- Combined Effects

In addition, extensive modeling updates and revisions have been developed for the traditional propagation factors such as

- Rain Attenuation
- Atmospheric Gaseous Attenuation
- Ionospheric Scintillation
- Frequency Scaling
- Worst Month, and
- Site Diversity.

Section 2 provides detailed step-by-step procedures for all of the new models and for the updated procedures as provided by the authors.

The first two subsections of Section 2 present prediction methods for satellite links operating below 3 GHz (primarily ionospheric effects), and prediction methods for satellite links operating above 3 GHz (primarily tropospheric effects), respectively. The third subsection presents prediction methods for radio noise. The fourth subsection describes several general modeling procedures, including statistical considerations, frequency scaling and elevation angle scaling. The final subsection presents models for the restoration of links subject to propagation impairments, including site diversity, orbit diversity and adaptive FEC.

Section	**Topic**
2.0	INTRODUCTION TO SECTION 2
2.1	PREDICTION METHODS FOR SATELLITE LINKS OPERATING BELOW 3 GHz
2.1.1	Total Electron Content
2.1.2	Faraday Rotation
2.1.3	Time Delay
2.1.5	Ionospheric Scintillation

2.1.6	Auroral Absorption
2.1.7	Polar Cap Absorption
2.1.8	Summary – Ionospheric Effects Prediction
2.2	PREDICTION METHODS FOR SATELLITE LINKS OPERATING ABOVE 3 GHz
2.2.1	Atmospheric Gaseous Attenuation
2.2.2	Cloud Attenuation
2.2.3	Fog Attenuation
2.2.4	Rain Attenuation
2.2.5	Rain Depolarization
2.2.6	Ice Depolarization
2.2.7	Wet Surface Effects
2.2.8	Scintillation
2.2.9	Worst Month Statistics
2.2.10	Fade Rate and Fade Duration
2.2.11	Combined Effects Modeling
2.3	RADIO NOISE
2.3.1	Specification of Radio Noise
2.3.2	Noise from Atmospheric Gases
2.3.3	Sky Noise Due to Rain
2.3.4	Sky Noise Due to Clouds
2.3.5	Noise From Extra-terrestrial Sources
2.4	GENERAL MODELING PROCEDURES
2.4.1	Application of Statistical Data
2.4.2	Frequency Scaling and Attenuation Ratio
2.4.3	Elevation Angle Scaling
2.4.4	Simultaneous Scaling
2.5	LINK RESTORATION MODELS
2.5.1	Site Diversity
2.5.2	Orbit Diversity
2.5.3	Link Power Control
2.5.4	Adaptive FEC
2.6	REFERENCES – SECTION 2

Table 3. Contents of Section 2 PREDICTION

The principal topics and associated subsection numbers for Section 2 are listed in Table 3.

Section 3 APPLICATIONS

A wide array of new satellite applications has appeared in the decade since publication of the last handbooks. Each application has unique design and performance characteristics requiring new approaches for the evaluation of propagation effects. Also, the extension of satellite communications to non-geosynchronous orbit (NGSO) constellations has added a new level of concern on the proper evaluation of link conditions for proper system operation.

The last decade has seen a proliferation of VSAT (very small aperture terminal) systems in the Ku-band, designed primarily for data applications. The VSAT typically are low margin systems, with margins of 1 to 3 dB. VSAT networks can be global, and operate in the domestic and international fixed satellite service (FSS) bands.

Direct Broadcast Satellites (DBS) also operating in the Ku-band provide direct-to-home entertainment video services. DBS systems are one of the fastest growing segments of the satellite industry. They are multi-channel digital systems with small (0.6m) rooftop type antennas. DBS systems are deployed in the U.S., Europe, Japan.

The past few years have also seen the initiation of rapid development of the Ka-band for a range of applications. Ka-band systems filed with the U.S. Federal Communications Commission (FSS) number fourteen employing geosynchronous orbit (GSO) satellites and three employing non-geosynchronous orbit (NGSO) satellites. Ka-band applications to the International Telecommunications Union Radiocommunicaitions Sector (ITU-R) have been tendered by twenty-one countries, with over 380 GSO satellites and eight countries have filed for over 200 satellites in NGSO constellations. The Ka-band is also allocated for feeder links for NGSO systems, including NGSO/FSS, NGSO/FSS/MSS, and NGSO/MSS services.

Another area of rapid development involves "Big LEO" mobile satellite personal communications systems. The big LEO systems are NGSO constellations, with 10 to 66 satellites, and operate in low earth orbit (LEO), medium earth orbit (MEO) and elliptical earth orbit (HEO). The primary service of the Big LEO systems is personal voice communications. The service links operate in the bands 1610-1626.5 MHz (uplink) and 2483.5-2500 MHz (downlink). They operate with multiple satellite antenna beams, and employ CDMA or TDMA/FDMA access techniques

"Little LEO" mobile satellites systems are smaller in size and in capabilities than the big LEO systems. They provide lower rate services including paging, messaging, and position location (no voice). They operate in NGSO (LEO) constellations of 20 to 24 satellites. The service links operate in the137-138, 148-149.9, 400-401 MHz bands.

The last year has seen the first interest in satellite systems operating in the so-called Q-band or Q/V-band. These systems operate in the FSS allocated bands of 37.5 - 40.5 GHz (downlink) and 47.2 - 50.2 GHz (uplink). Twelve organizations filed fourteen Q/V-band systems with the FCC in September 1997. These systems are designed to provide broadband multimedia services, VSAT and direct to home services. Q/V-band systems typically have higher data rates than Ku or Ka band systems, with data rates of up to 3 GBPS being considered. The proposed systems include GSO, NGSO, and mixed constellations.

Each of these applications has unique propagation characteristics. Section 2 of this handbook provides the tools to evaluate the propagation degradations of these systems, and this section, Section 3, offers "roadmaps" to adequately identify and analyze the specific propagation factors important to the application.

Another area where recent developments have changed the "playing field" in satellite communications is the increased emphasis on spectrum sharing and interference mitigation**.** The explosion in global satellite systems has required the system designer to include spectrum sharing as a critical part of the system design. The radio spectrum is a fixed and limited resource, and the available bandwidth in most of the bands allocated for satellite applications is not adequate for all of the systems under consideration for deployment. Sharing is required, and often, if band segmentation cannot be employed, mitigation techniques including power control and exclusion zones have to be evaluated. Also, the sharing of GSO and NGSO systems operating in the same allocated bands adds another critical element to the spectrum sharing process.

The inclusion of the appropriate propagation effects in the desired and the interfering links is essential to an acceptable solution. The models and procedures described in this handbook are elements of a comprehensive spectrum sharing process that often includes simulations and analytic procedures of the full range of applications and satellite orbits.

Section 3 begins with an overview of general link analysis procedures for satellite communications systems. Design considerations and recommendations for the selection of a rain attenuation prediction model are included. Section 3.2 covers propagation effects on systems operating below 3 GHz. Sections then follow on Ku-band systems, Ka-band systems, Q/V-band systems, and direct broadcast systems. A discussion on propagation considerations for non-geosynchronous (NGSO) is also included.

Section	Topic
3.0	INTRODUCTION TO SECTION 3
3.1	APPLICATION OF PREDICTION MODELS TO SYSTEM DESIGH AND PERFORMANCE
3.2	PROPAGATION EFFECTS ON SATELLITE SYSTEMS OPERATING

	BELOW 3 GHZ
3.3	PROPAGATION EFFECTS ON KU-BAND SYSTEMS
3.4	PROPAGATION EFFECTS ON KA-BAND SYSTEMS
3.5	PROPAGATION EFFECTS ON Q/V-BAND SYSTEMS
3.6	PROPAGATION EFFECTS DIRECT BROADCAST SATELLITE SYSTEMS
3.7	PROPAGATION EFFECTS CONSIDERATIONS FOR NGSO SYSTEMS
3.8	REFERENCES – SECTION 3

Table 4. Contents of Section 3 APPLICATIONS

The principal topics and associated subsection numbers for Section 3 are listed in Table 4.

Summary and Future Plans

The latest version of the NASA Propagation Effects Handbook for Satellite Systems Design was delivered to NASA JPL on October 23, 1998. Revision 1 was released in February 1999. JPL has recently negotiated with ITT Industries for an extension contract to update the handbook. Revision 2 to the Fifth Edition will include corrections and minor updates based on an on going peer review; the addition of an index and list of symbols; the inclusion of the complete ACTS data base; and updates to ITU-R and other prediction models that have occurred in the last twelve months.

The Fifth Edition of the Propagation Effects Handbook for Satellite Systems Design continues the long process of a continuing commitment to provide a comprehensive reference document which provides the latest information on atmospheric propagation effects and how they impact satellite communications system design and performance.

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