ISTF/3 – WP /9
Agenda Item 5 (a)
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International Civil Aviation Organization

THE THIRD MEETING OF IONOSPHERIC STUDIES TASK FORCE (ISTF/2)

15 – 17 October 2013, Seoul, Republic of Korea

국토교통부
Ministry of Land, Infrastructure and Transport

Agenda Item 5: Review of progress of tasks and related action items

(a) Task 1- Data Collection

GUIDANCE MATERIAL ON SCINTILLATION MEASUREMENTS

(Presented by Japan)

SUMMARY

This working paper presents the guidance material on ionospheric scintillation data collection in the low latitude region in response to the Action Item 1 identified by the second meeting of the Ionospheric Studies Task Force (ISTF/2).

1. INTRODUCTION

1.1 The second meeting of the Ionospheric Studies Task Force (ISTF/2) held in Bangkok, Thailand from 15 to 17 October 2013 identified an Action Item:

> **ACTION ITEM 1:** ISTF should develop a guidance material on collection of scintillation data at strategic locations. Preliminary draft of the guidance material should be available by November 2012 and the final guidance material, incorporating all the recommended changes, should be available by December 2012.

1.2 This working presents the guidance material on collection of scintillation data.

2. DISCUSSION

2.1 Since the ISTF/2 meeting, the guidance material of the inospheric scintillation data collection has been discussed and revised through the ICAO ISTF Forum. The first draft was prepared by Japan and presented at the forum on 27 November 2013.

2.2 The draft has been reviewed through the forum and revised repeatedly. The guidance material has been finalized on 8 May 2013 as Version 1.1b. The final version of the guidance material on ionospheric scintillation data collection is attached to this working paper as Attachment 1.

3. ACTION REQUIRED BY THE MEETING

3.1 The meeting is invited to do the following:

a) adopt the material on ionospheric scintillation data collection presented in this paper as a guidance material of this task force.

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ATTACHMENT 1

- Guidance on Ionospheric Scintillation Observation in the Low-latitude Region (Version 1.1b)

Attachment to ISTF/3 – WP/9

Guidance on Ionospheric Scintillation Observation in the Low-latitude Region

Prepared ~~In preparation~~ by Susumu Saito

~~06~~ 08 ~~Dec~~ May 2013~~2~~

Version 1.1b~~0.3~~

1. Background

The second meeting of Ionospheric Studies Task Force (ISTF/2) noted the limited scintillation monitoring facilities established in the region, and decided to develop a guidance material on collection of scintillation data at strategic locations (Action Item 1). This document has been developed to address the AI-1 of ISTF/2.

There are two types of ionospheric scintillations in GPS measurements, amplitude and phase scintillations. Amplitude scintillation refers to rapid fluctuation in signal intensity (or carrier-to-noise ratio, C/N0) measured by a receiver, while phase scintillation refers to rapid fluctuation in the carrier-phase measurements. Levels of amplitude and phase scintillations are commonly represented by the standard deviations of amplitude and phase, respectively S4 and σ_φ, in a certain time period (typically 1 min).

For the amplitude scintillation, rapid sampling of C/N0 is necessary, while rapid carrier-phase measurements are required for the phase scintillation. Furthermore, GPS receivers for phase scintillation measurements need to be equipped with a highly stable clock (oscillator) such as OCXO (oven-controlled crystal oscillator) to distinguish the phase fluctuations due to ionospheric scintillation and clock (oscillator) noise.

Both types of ionospheric scintillations are caused by plasma irregularities in the ionosphere. In the low-latitude regions where the background electron density is high and plasma drift velocity is relatively slow, the amplitude scintillation is dominant. In this guidance, therefore, the amplitude scintillation is focused on. The way of estimating the amplitude scintillation index (S4 index) is given in Appendix A.2.

2. Receiver performance

2.1 Receiving frequency

Since only the GPS L1 (1.57542 GHz) is currently used, GPS L1 single-frequency receivers satisfying other performance requirements in this section are acceptable. In addition to GPS, however, receivers should be capable of GLONASS and SBAS GEO satellites for wide coverage of the sky.

For the use of the L5 frequency in the future, receivers capable of tracking L1 and L5 signals would be a good choice.

If a receiver could track L2 frequency, it could be used to measure ionospheric delays (or ionospheric total electron contents (TECs)).

2.2 Receiver clock

Since the amplitude scintillation is of interest, a highly stable clock is not necessary, but a standard clock such as TCXO (temperature compensated crystal oscillator) is enough.

2.3 Sampling rate

The amplitude scintillation is caused by the Fresnel diffraction due to the ionospheric irregularities. The typical scale size causing the Fresnel diffraction (D_F) is described as

$$D_F = \sqrt{2\lambda h} \tag{1}$$

where λ is the wavelength of the radio wave (0.19 m for the GPS L1 frequency) and h the height of the irregularities (typically 300-400 km). Thus, the typical scale size is 300-400 m. The amplitude will fluctuate at the Fresnel frequency

$$f_F = V / D_F \tag{2}$$

where V is the drift velocity of the irregularities. Since the drift velocity of plasma irregularities (V) is typically 100-200 m/s, the amplitude will fluctuate at 0.25-0.67 Hz.

According to the sampling theory, the sampling rate of the amplitude should be at least twice as fast as the Fresnel frequency, 0.5-1.33~~7~~ Hz. Considering that the spectrum of amplitude fluctuation contains higher frequency components, the sampling rate should be much higher than the Fresnel frequency. It is common to sample the amplitude at 20 Hz or more. It should also be noted that the default sampling rate of the amplitude by the widely used GSV4004B receiver is 50 Hz.

The raw amplitude measurements at high sampling rates can be recorded. However, it would take a lot of file size. Therefore, the raw amplitude measurements could be discarded after calculating and recording scintillation intensity, although the raw amplitude measurements data would still be useful for future re-analysis and irregularity drift measurements with closely spaced scintillation receivers.

If the ionospheric delay is desired to be derived, both~~t~~ the pseudo-range and carrier-phase need to be sampled. However, the sampling rates of them do not have to be the same as the amplitudes, but can be much slower than that of the amplitude. The typical sampling rate for the ionospheric delay measurements is 1 sec. (For GBAS, the minimum sampling rate of a ground subsystem is 2 Hz, though.)

TEC measurements can also be used to derive another index of ionospheric irregularities: the rate of TEC Index (ROTI). ROTI is defined as the standard deviation of rate of TEC in a certain time period, typically 5 min [2]. ROTI is another indicator of ionospheric irregularities that can be derived from standard low sampling rate dual-frequency receiver measurements. The way of estimating ROTI is given in Appendix A.3.

2.4 Multi-path effect avoidance

The measured amplitude often fluctuates at low elevation angles due to multi-path effects and result in artificial enhancements in the scintillation level. There are two ways to eliminate the multi-path effects. One is simply to set a higher elevation mask such as 30º. However, it would have a drawback of loosing data at low elevation angles where the path length in the ionosphere is long and more scintillation is expected.

Alternatively, the standard deviation of the code-carrier divergence (sigma-CCD) can be utilized. The code-carrier divergence is the difference between the rates of change in pseudo-range and carrier-phase measurements. When there is no multi-path and ionospheric effects, the rates of change in pseudo-range and carrier-phase changes will be the same, except for ambient and receiver internal noises.

The multi-path signal generally accompanies much larger sigma-CCD than ionospheric scintillation signal, which can be used to distinguish between scintillation enhancements by multi-path and ionospheric irregularities [1]. If a sigma-CCD value calculated for the same period as the S4 index exceeds a certain limit, the signal is likely to be affected by multi-path effects. To do this, the pseudo-range and carrier-phase need to be sampled at a certain rate, such as 1 Hz. Sigma-CCD can be calculated afterwards if the pseudo-range and carrier-phase are recorded, while some receivers such as GSV4004B can calculate sigma-CCD internally and record it. The way of deriving the sigma-CCD is given in Appendix A.2.

2.5 Other useful measurements

The satellite azimuth and elevation angles are not essential, but will make post-analysis easier. The sampling rates of the azimuth and elevation angles can be as low as those of the pseudo-range and carrier-phase.

2.6 Summary

The receiver should be able to track at least GPS L1 frequency signals. Tracking capability of GLONASS and SBAS GEO satellites are very useful.

The receiver do not have to be equipped with a highly stable clock (oscillator) as long as it is used for the amplitude scintillation measurements, which is the case in the low latitude regions.

The most important value to be recorded for the low latitude ionospheric scintillation is the amplitudes (C/N0) of the signal for each satellite. The sampling rate should be much higher than the Fresnel frequency and typically 20 Hz or more. Once the scintillation intensity is calculated and recorded, the raw amplitude measurements data can be discarded, unless future re-analysis or irregularity drift velocity measurements are not planned.

The pseudo-range and carrier-phase can be recorded at relatively low rates than the amplitude, such as 1 Hz. They are not mandatory, but useful to distinguish between ionospheric scintillation and multi-path signals.

The satellite azimuth and elevation angles are not essential, but will make post-analysis easier, if recorded together.

3. Antenna

3.1 Antenna frequency

Antenna should be able to track signals corresponding to the signals which are desired to be tracked by the receiver.

As described in 2.1, an antenna capable of tracking L1 and L5 signals is a good choice.

3.2 Antenna type

To avoid the multi-path effect as much as possible, a choke-ring antenna or others with equivalent multi-path-resistant performance are preferable. Simple antennas could be used, but with a drawback of lower data availability especially at low elevation angles.

3.3 Antenna environment

Antennas should be located at places with the open sky without obstacles that may shadow satellites down to the elevation angle as low as possible.

The antenna site should be free from obstacles as wide as possible to avoid multi-path effects. Practically, it is very difficult to find ideal antenna locations. Therefore, the sigma-CCD filtering is very useful to enhance data availability under the multi-path conditions.

For example, installation of receiver in localizer building is recommended owing to its strategic location which is usually free from multipath. ~~Though~~ However, seaside runways are at disadvantage. We have observed more multipath effects in scintillation at sites surrounded by ocean.

4. References

[1] Van Dierendonck, A. J., and Q. Hua, Measuring ionospheric scintillation effects from GPS signals, proceedings of ION 57th Annual Meeting, 391-396, 2001.

[2] Pi, X., A. J. Mannucci, U. J. Lindqwister, and C. M. Ho, Monitoring of global ionospheric irregularities using the worldwide GPS network, Geophysical Research Letters, 24, 2283-2286,1997.

Appendix A. Parameter estimation

A.1 Amplitude scintillation index (S4 index)

The amplitude scintillation index (S4 index) is defined as a normalized standard deviation of C/N0 as given by:

$$S4 = \sqrt{\frac{\langle s_i^2 \rangle - \langle s_i \rangle^2}{\langle s_i \rangle^2}} \qquad (3)$$

where < > denotes average , and s_i is the C/N0 in linear scale (not in dBHz) of the i-th satellite. The linear-scale C/N0 (s_i) is related to the C/N0 in dBHz (c_i) as:

$$s_i = 10^{(0.1 \times C_i)} \qquad (4)$$

The period of taking average depends on the time scale of interest. It is common to calculate S4 every 1 min (i.e., the averaging period of 1 min).

A.2 Sigma-CCD

Sigma-CCD is defined for each satellite as the standard deviation of code-carrier divergence as given by:

$$SigmaCCD_i = \langle d_i^2 \rangle - \langle d_i \rangle^2 \qquad (5)$$

where d_i is the code-carrier divergence of the i-th satellite as given by:

$$d_i = \left(\rho_i(t+\tau) - \rho_i(t)\right) - \left(\varphi_i(t+\tau) - \varphi_i(t)\right) \qquad (6)$$

where $\rho_i(t)$ and $\varphi_i(t)$ are respectively the pseudo-range and carrier-phase measurements of the i-th satellite at a time t, and τ is the sampling interval of the pseudo-range and carrier-phase.

The period of taking average should be the same as S4 index, and typically 1 min. The sampling interval of the pseudo-range and carrier-phase is typically 1 sec.

A.3 Rate of TEC index (ROTI)

ROTI is defined for each satellite as the standard deviation of rate of TEC (ROT) as given by:

$$ROTI_i = \langle ROT_i^2 \rangle - \langle ROT_i \rangle^2 \qquad (7)$$

where ROT_i is the rate of TEC of the i-th satellite in the unit of TEC/min as given by:

$$ROT_i(t) = \left(TEC_i(t) - TEC_i(t-\tau)\right)/\tau \qquad (8)$$

where τ is the sampling interval.