Statistical analysis in different geomagnetic latitude and satellite communication system impact by Ionospheric scintillation

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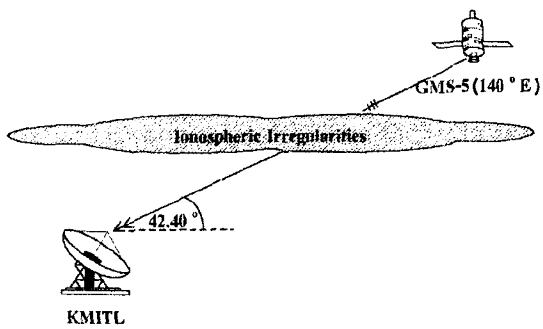
Abstract: This paper presents the statistical analysis and the effects of the ionospheric scintillation to the satellite communication system. By receiving 1.694 GHz carrier wave of telemetry signal transmitted from Geostationary Meteorological Satellite (GMS-5) at both of King Mongkut's Institute of Technology Ladkrabang, Bangkok, and Chiang Mai University, Thailand, in order to study the characteristics of Ionospheric scintillation in case of different geomagnetic latitude position; the statistical analysis of S_4, fade duration, message reliability and fade rate can be obtained. The data was analyzed from February 2000 to January 2001.

1. Introduction

The Ionospheric scintillation occurs when the ionospheric irregularities propagate through the satellite signal, as shown in Figure 1. Therefore both of amplitude and phase of satellite signal are varied. In this research, only amplitude fluctuation is considered. This paper is scope to the ionospheric scintillation characteristics effected on satellite signal. The morphological results can inform the intensity of the scintillation that severs the amplitude signal randomly. The signal amplitude fluctuates above the mean reference level highly can lead to the large enhancement that can increase the inter-modulation noise and result in a worsening of C/I (Carrier to Interference). On the other hand, when the signal fluctuates below the mean level exceeding system threshold, the signal fading can occur. The results of the scintillation occurrence, the diurnal and seasonal variation and signal fading are the important data to obtain the communication planning via satellite link or system margin design appropriate to the real situation of each station.[1]

The objective of this research is study the statistical analysis of ionospheric scintillation that effects 1.694 GHz satellite signal for different geomagnetic latitude position and approximate the system impact. Moreover, the system performance evaluation will be considered to show the system vulnerability under ionospheric scintillation effects.



"Figure 1. Ionospheric irregularities effects satellite signal"

2. Experimental and Analytical Process

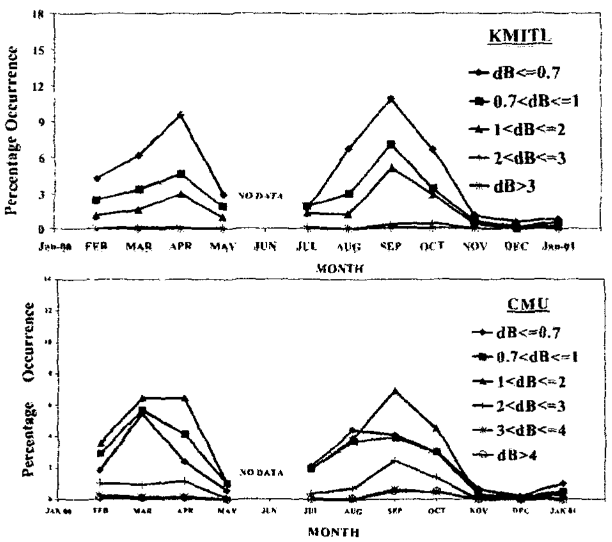
Our experiment has been carried out from February 2000 receiving 1.694 GHz carrier wave of the telemetry signal transmitted from GMS-5 satellite. The position of this satellite is at 140° E; the receiving station is at KMITL (100.8° E, 13.7° N, 2.8° N geomag) and also at CMU (99.0° E, 18.8° N, 7.9° N geomag). The 1.8 meters parabolic antenna has the elevation angle of 42.40°. The received signal is collected every 0.02 seconds but using re-sampling data 10 seconds for analysis. One scintillation's occurrence is counted every 3 minutes period of scintillation event that the fluctuating amplitude exceeds 0.5 $dB_{P\text{-}P}$. Scintillation data for one year, February 2000 to January 2001, used for analyzing scintillation occurrence and comparing between both stations is presented here.

From the intensity analysis, the diurnal and seasonal variation of the occurrence, the amplitude variation and S_4 index distribution can be obtained. For frequency structure analysis of scintillation events, the 5 minutes period of the raw data, 0.02 seconds sampling, is taken into account by Fast Fourier Transform. The power spectral analysis of scintillation has 0.95 % confidential limit. The characteristics of ionospheric irregularities can be studied from the part of power spectral of that scintillation event. Moreover, in order to study about the effects of communication system due to scintillation, the fade analysis is also considered. Additionally, the signal fading is considered to estimate the fade duration and message reliability by using resample 0.2 seconds scintillation data and analyzed by level crossing technique.

3. Morphological results

3.1 Scintillation Occurrence

The scintillation occurrence observing for one year data is described in this section. The seasonal variation of each amplitude fluctuation levels of both stations presents below. From figure 2a and 2b, the occurrence numbers of scintillation at KMITL is maximum in April and maximum again in September. On the other hand, at CMU station, the scintillation occurrence is maximum in March and September corresponding to the seasonal variation of vernal and autumn equinox respectively. In June, there is not any scintillation signal at both stations due to receiver system broke down.

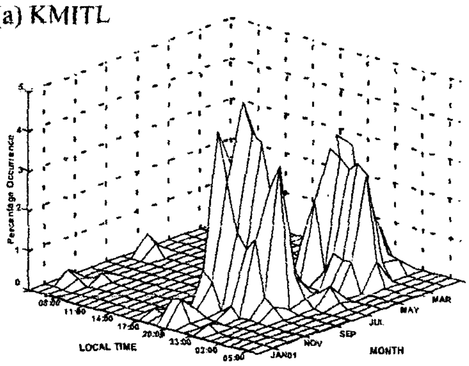


"Figure 2a and 2b. Seasonal variation of amplitude scintillation "

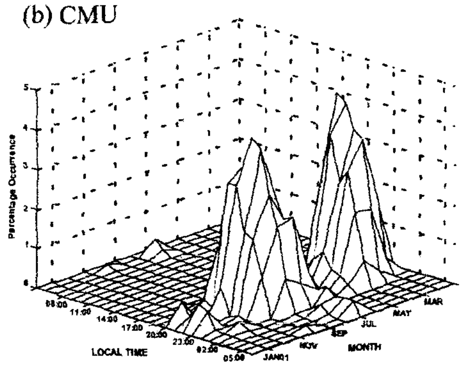
When comparing the scintillation strength of both stations, we found that the scintillation occurring at CMU is higher intensity than BKK. The high amplitude fluctuation levels more than 2 to 4 dB can be observed and the signal usually fluctuates between 1-2 dB at CMU. On the other hand, the high fluctuation level is rarely observed and the amplitude of signal fluctuation is mostly less than 1 dB at BKK station.

For the diurnal variation, the time when scintillation usually occurs is around 19:00-02:00 LT(Local Time). In some days, especially in July and December, scintillation can occur after that time until morning of the next day. This is due to the anomaly ionospheric irregularities and solstice, as shown in figure 3a and 3b. Figure 4a and 4b describe about the intensity of scintillation index S_4. The high levels of S_4 index distribute continuously at CMU. The levels are between 0.15 to 1. On the contrary, the intensity levels do not exceed 0.6 at KMITL. These can also confirm that the stronger scintillation occurring at CMU more than at KMITL corresponding to the geomagnetic latitude.

(a) KMITL

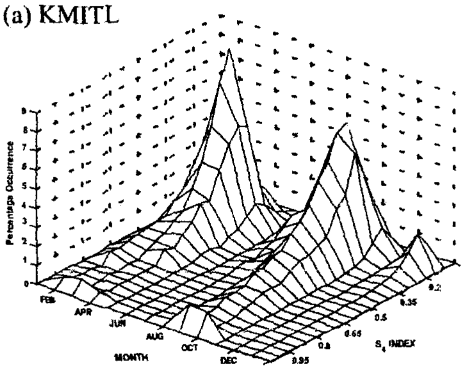


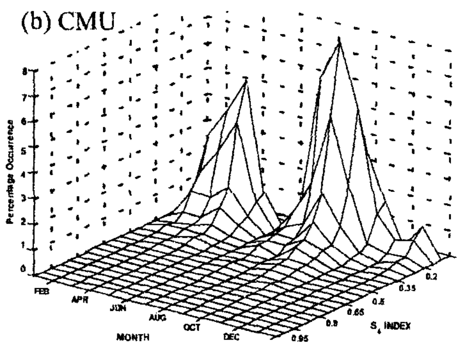
(b) CMU



"Figure 3a and 3b. Diurnal and seasonal variation of scintillation occurrence"

(a) KMITL

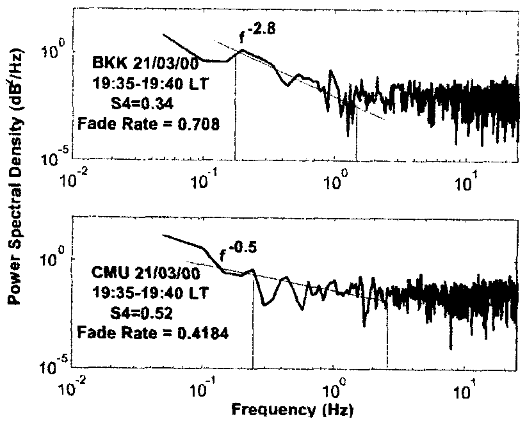




"Figure 4a and 4b. Long-term distribution of S_4 index "

3.2 Frequency Structure of Amplitude Scintillation

The power spectral density of scintillation events is considered in this part. According to figure 5, three main portions of scintillation power spectral can be explained. First, the flat low frequency, the high frequency roll-off and last part, noise floor. Fresnel frequency and noise floor starting frequency are the transition frequencies between the flat low frequency-the high frequency roll-off part and the high frequency roll-off the noise floor part respectively. The high frequency roll-off part contains the detail about Ionospheric irregularities [2]. The slope of this part; υ , one component of the spectral index, can be defined by the asymptotic line using log linear least square. The power number of $\mathbf{f}$ informs the spectral index, $\mathbf{f}^{-n}$ where $n = -\frac{(2+\rho)}{4}$; and $\rho = \upsilon + 1$ where ρ is the spectrum index of irregularities and υ is the slope of high frequency part [3].



"Figure 5. Power spectral analysis of scintillation events"

In addition to the spectral index, the fade rate of scintillation signal is also estimated by the inverse of the bandwidth between fresnel frequency and noise floor starting frequency. The fade rate defines the time period when that scintillation event spends for one fluctuating cycle. Figure 5 compares the power spectral density of two scintillation events. CMU event is stronger than BKK; S_4 index level is higher, leading to the wider bandwidth of high frequency part. The fade rate of CMU event is 0.4184 describing that scintillation signal fluctuating one average period spends 0.4184 s. From Table 1, the fade rate becomes decreasingly when S_4 index increases.

"Table 1. Presents the statistics results obtained from power spectral analysis of four scintillation events."

Scintillation Events	S_4	Slope (v)	Fresnel Frequency (f_F mHz)	Noise Floor Frequency f_{NF} (Hz)	Fade rate $t=(f_{NF}-f_F)^{-1}$
BKK 21/03/00	0.34	-2.8	187 mHz	1.60 Hz	0.7384
BKK 19/09/00	0.45	-2.4	193 mHz	2.43 Hz	0.4462
BKK 22/09/00	0.48	-2.6	147 mHz	2.63 Hz	0.4022
CMU 21/03/00	0.52	-0.5	243 mHz	2.63 H	0.4184

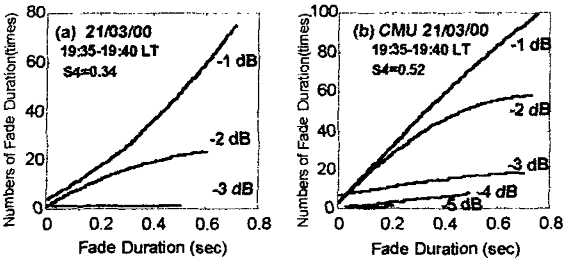
4. Effects of Ionospheric scintillation on communication system

In this section, the fade duration and the message reliability is considered in order to estimate this range or design the fade margin of system appropriately to each station. The 0.02 s raw data is re-sampled and changed to 0.2 s data for analysis.

4.1 Fade Duration Analysis

According to this observation system, assume the fade level, –1 to –6 dB, suitably for this low margin system. Then determine the fade duration by using the level crossing data technique [4], counting the numbers of time when signal exceeding the specific fade level. The numbers are divided by two because the signal crosses the specific fade level twice in one fluctuation.

Figure 6. plots the cumulative fade duration that does not exceed the fade duration in X-axis. The stronger scintillation, Figure 6b, can determine the numbers of fade duration in various fade levels more than others. For instance, the fade duration of the signal less than 0.6 s exceeding fading level –2 dB occurred about 55 times.



"Figure 6. Fade duration simulation in each fading levels"

4.2 Message Reliability Analysis

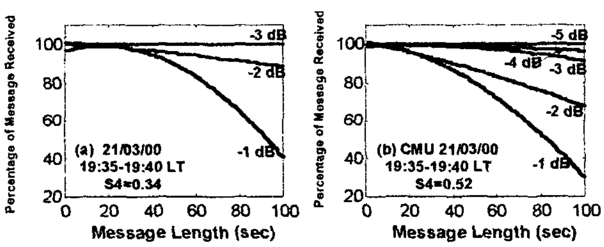
The message reliability can estimate the increasing of system margin, which is required over the specific fading level by CDF to obtain a probability of receiving message perfectly. The message reliability evaluation can be described as followed for any threshold level.

$$\frac{TotalTime-\left(\sum T_{fade}(T \ge T_0)+n_{fade}(T < T_0)T_0\right)}{TotalTime}\times 100\% \quad (1)$$

where T_{fade} is the fade duration that is equal to or longer than message length, T_0

n_{fade} is the number of fade that its duration time is shorter than message length

$Total\ Time$ is all possible times of entire sample segments



"Figure 7. Message Reliability simulation in each system margin levels"

Consequently, the percentage of the message that received perfectly can be plotted against the message length in unit second as presented in Figure 7. From the figure, we can observe that message reliability decreases when the message length increases and it falls off more rapidly when fade level increases. For example, when transmitting data 80 s length, if system margin is considered at –2 and –4 dB, then the percentage of message reliability of Figure 7b is about 75% and 95% respectively. Furthermore, if transmit data more shorter, 40 s length; the percentage of the message reliability is higher than ones as mentioned previously.

5. Conclusion

1. The amplitude scintillation of 1.694 GHz signal is the nighttime scintillation. The severe effects usually occur in April (KMITL) or March (CMU) and September depending on vernal and autumn equinox respectively.
2. The scintillation occurring at CMU (7.9°N) is stronger than KMITL (2.8°N) because CMU's geomagnetic latitude position is closer to the equatorial anomaly (±15° over geomagnetic equator), that causes the variation of the irregularities much more than KMITL.
3. Power spectrum of scintillation contains the detail about the irregularities. The average fade rate and slope determined from this can perform the variation of the irregularities and provide a basis of time/space diversity technique evaluation idea.
4. Distribution of fade duration for various fade margin levels can characterize the scintillation effects on communication channel. If the fade duration is longer than the message length and the fade depth is below the system threshold, the information can be lost fully or partially as performing by message reliability.
5. Message reliability decreases when the message length increases, and it falls off more rapidly as the fade margin increase. The perfect message can be received only during the time interval when the signal level is greater than the fade margin the threshold level of the given system.

6. Reference

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