International Civil Aviation Organization

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

15 – 17 October 2012, Bangkok, Thailand

Agenda Item 3: Review Status of State's Activities

EFFECT OF SCINTILLATION ON THE GAGAN GEO SIGNALS - CHALLENGES IN INTEGRATING GEOSTATIONARY SATELLITE WITH UPLINK STATION

(Presented by C R Sudhir, General Manager (GAGAN), Airports Authority of India)

SUMMARY

The GPS Aided GEO Augmented Navigation (GAGAN) is the Indian Satellite Based Augmentation System (SBAS) program. The integration of the Indian Land Uplink Station (INLUS) with the Indian Geostationary satellite, GSAT-8, was carried out during July'11 to January'12. This is the first time that a GEO is integrated with a ground station in the equatorial region for an operational SBAS. The integration of the GEO with the uplink station is a technically challenging activity which requires several iterations to tune the parameters to meet the stringent system requirements and also because India lies in the equatorial region.

During the integration process it was observed that from mid of August onwards both L1 (1575.42MHz) and L5 (1176.45MHz) downlink signals were affected and the carrier to noise ratio was dropping so low as to unlock the GPS receiver used in the uplink station. This drop was experienced daily from 1600UTC to 1900UTC. This effect became more and more predominant during the equinox (23-SEPT-2011). The GPS measurement data was analyzed and it was found that this was due to scintillation, which was happening after post dusk and was affecting L1 and L5 differently due to the difference in frequency.

A study was conducted to analyze the severe effect on L5. This test concluded that large drop in C/N0 for the BPSK modulated L5 signal may be due to the higher chipping rate for L5 signal i.e. 10MHz compared to the lower chipping rate of 1MHz for the L1 signal. A separate study is required to understand how the receiver processes the signals with different chipping rate and compute the carrier to noise ratio. This paper describes the technical challenges involved in the integration of GSAT-8 with the Uplink Station.

1. INTRODUCTION

1.1 GPS Aided GEO Augmented Navigation (GAGAN) is a planned implementation of Satellite Based Navigation System being developed jointly by Airports Authority of India (AAI) and Indian Space Research Organization (ISRO), to deploy and certify an operational Space Based Augmentation System (SBAS) for Indian Flight Information Region (FIR), with expansion capability to neighboring FIRs. GAGAN system will provide corrections to the Global Positioning System (GPS) signal to meet the accuracy, integrity, availability and continuity requirements prescribed for aviation. "GAGAN" in the ancient Indian language, Sanskrit means the Sky; hence the name aptly suits the project. GAGAN Project was conceived in the year 2001 and planned in two phases: Phase I: Technology Demonstration System (TDS) and Phase II: Final Operation Phase (FOP).

1.2 The TDS phase was undertaken to demonstrate and establish India's technological capability to augment GPS data. TDS phase was successfully completed in August 2007 with implementation of a minimum configuration system to demonstrate the capability of the SBAS over limited region of the Indian airspace to serve as proof of concept. The performance objective was to meet the limited ICAO SARPs requirements. The integrity was not targeted as a goal as only skeleton ground elements were deployed, however analysis were conducted to study the integrity. The GAGAN Final Operation Phase (FOP) is implemented in a spiral deployment methodology, building incrementally on the TDS phase equipment and architecture, using lessons learned, and data generated from TDS phase to meet the set objective of providing enroute, non-precision approach and precision approach service over the designated service volume. The GAGAN-FOP phase is intended to install, certify and operate fully operational SBAS system meeting ICAO specifications. The GAGAN-FOP system will have 15 Reference stations, Two Master Control Centers and three Uplink Stations. Almost all Ground Segments have been installed, tested and integrated with GEO satellite GSAT-8. Although the GAGAN signal-in-space is currently available for non-aviation users, the certified GAGAN signal-in-space for aviation users within the defined service volume will be available with availability of the entire system including appropriate redundancies and safety assurance mechanisms by July 2013.

2. DISCUSSION

2.1 The process of GEO Integration involves interfacing of the Signal Generation Subsystem (SGS), the Radio Frequency Unit (RFU) and the Geostationary Earth Orbit (GEO) satellite. This procedure ensures, from an SGS perspective, that the ground station is properly integrated with the GEO satellite.

2.2 During the integration process, it was observed that from middle of August onwards both L1 (1575.42MHz) and L5 (1176.45MHz) downlink signal were affected and the carrier to noise ratio were falling so low as to unlock the GPS receiver used in the uplink station. The drop in the C/N0 for L5 was about 25-30dB from the nominal value and for L1 it was about 5-10dB below the nominal value. This drop was experienced daily from 1600UTC to 1900UTC. The effect became more and more predominant during the equinox period starting from end of September to beginning of October 2011. The GPS measurement data was analyzed and it was found that this observed drop may be due to scintillation, which is happening after post dusk and was affecting L1 and L5 differently due to the difference in frequency.

2.3 A study was conducted to analyze the severe affect on L5. This was done by removing the modulation from carrier and up-linking the pure carrier in C-band to the satellite and receiving the pure carrier in the L-band on a spectrum analyzer. This study showed that the severe drop in C/N0 is not observed when the pure carrier is received. The C/N0 drop was within the limit that is expected for the L1 and L5 frequency, i.e. L5 more affected than L1 due to the lower L5 frequency. This test concluded that large drop in C/N0 for the BPSK modulated L5 signal may be due to the higher chipping rate for L5 signal i.e. 10MHz compared to the lower chipping rate of 1MHz for the L1 signal.

2.4 Since this was a first experience receiving the L5 frequency using a GPS receiver, lot of analysis were carried out to understand the exact cause of the problem. Also the difference on the affect on the L1 and L5 frequency was also studied in detail. But the classical theory of computing the effect of ionosphere on the L1 and L5 signals were not holding good as the affect on L5 signals were much higher than expected. Since always this effect was seen after midnight local time it was concluded that the cause of the problem could be the scintillation, which is a post dusk phenomena.

2.5 Further studies made concluded that the modulation and chipping rate plays very important role in this phenomena which is due to the scintillation. Also the effect is more predominant on L5 due to the higher chipping rate of 10MHz and less predominant due to the less chipping rate of 1MHz.

2.6 In order to operate an uplink station for SBAS in the equatorial region it will be required to reduce the threshold for unlock in the GPS receiver to such an extent to avoid loss of lock during the equinox. This is done after practically collecting the data and fixing the threshold after analysis.

2.7 The data has been provided to OEMs to study the problem and come out with a solution. Also certain software changes have been incorporated in the system to take care of this phenomenon.

3. ACTION BY THE MEETING

3.1 The meeting is invited to note the challenges faced during GEO integration of GAGAN Uplink Station due to the effect of scintillation of GEO signals and the actions taken to overcome the effect of scintillation and successfully carry out the GEO integration process.

– – – – – – – – – – – – –

ATTACHMENT

UPLINK TO GEO INTEGRATION PROCESS

The process of GEO Integration involves interfacing of the Signal Generation Subsystem (SGS), the Radio Frequency Unit (RFU) and the Geostationary Earth Orbit (GEO) satellite. This procedure ensures, from an SGS perspective, that the ground station is properly integrated with the GEO satellite.
Before proceeding with the GEO integration process the following activities were completed to ensure that the ground station and the satellite meet all the requirements to qualify for GEO integration:

- Test and Evaluation (T&E) of Ground Uplink Station: in this activity, the ground station is thoroughly tested to ensure that it meets the requirement of phase noise, RF harmonics etc; and

- In Orbit Test (IOT) for the Navigation Payload: in this activity, the satellite parameters are thoroughly tested to ensure that they meet the SBAS requirement. Also the parameters like satellite delay, Frequency translation errors etc are measured and recorded.

The interfacing of the Signal Generation System and the RF Uplink System ensures that in the forward path the Klystron Power Amplifier (KPA) is fed with the required level and in the feedback path the GPS receiver receives the nominal input signal level. This is achieved by adjusting the variable attenuators introduced in the signal path and controlling the output of the Up convertor and the Test Loop Translator (TLT). This procedure will account for all the cable losses

All the Cable Delays are measured, documented and used as static parameters for the system. Once the ground system interfacing is completed, the parameters with respect to the Navigation transponder are measured and entered as static parameters. These parameters include the Satellite Delay and the Frequency Translation Errors. These parameters are measured in an iterative way until the final value is arrived. This involves measurement of preliminary value during the IOT and then updating the parameters after running the system continuously for longer periods. This may require four to five iterations till the results converge.

Once the static parameters are measured and updated in the system, the control loop tuning and the clock steering parameter tuning is done. This involves the tuning of Kalman Filter parameters and PID controller tuning. This will ensue that the GEO clock is driven towards the GAGAN network Time (GNT) and the downlink frequency for user in the L1 (1575.42MHz) is ensured by taking care of the satellite translation error and the Doppler between satellite and the uplink antenna.

CHALLENGES DURING GEO INTEGRATION

During the integration process, it was observed that from middle of August onwards both L1 (1575.42MHz) and L5 (1176.45MHz) downlink signal were affected and the carrier to noise ratio were falling so low as to unlock the GPS receiver used in the uplink station. The drop in the C/N0 for L5 was about 25-30dB from the nominal value and for L1 it was about 5-10dB below the nominal value. This drop was experienced daily from 1600UTC to 1900UTC. The effect became more and more predominant during the equinox period starting from end of September to beginning of October 2011. The GPS measurement data was analyzed and it was found that this observed drop may be due to scintillation, which is happening after post dusk and was affecting L1 and L5 differently due to the difference in frequency. Also, it was observed that the Kp index was on the higher side during this period. It was inferred from the data collected from different GAGAN reference stations across India that this effect is maximum near the magnetic equator and different stations experienced dissimilar signal drop due to the difference in geographical location. The Kp index variation for 23rd Sept 2011 and 15th March 2012 are shown in figures 1 and 2.

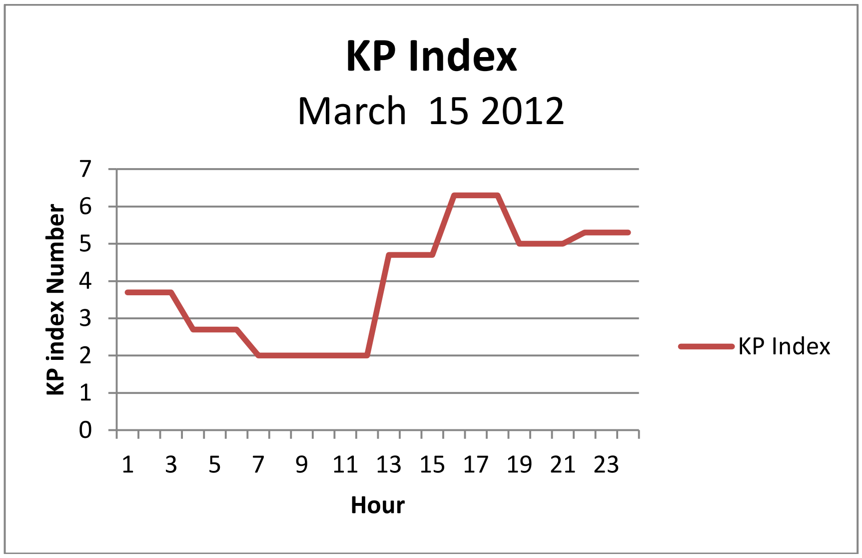

Figure1: Kp Index Variation 15th March 2012

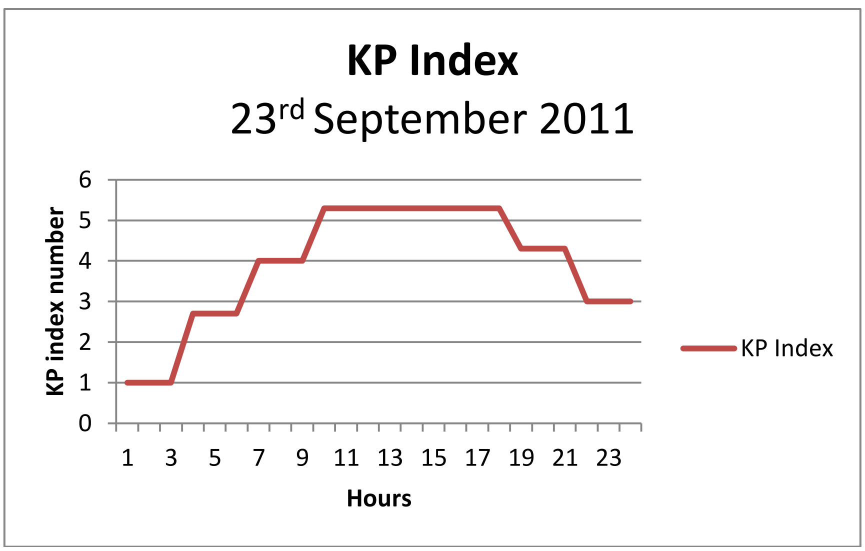

Figure 2: Kp Index Variation 23rd Sept 2012

A study was conducted to analyze the severe affect on L5. This was done by removing the modulation from carrier and up-linking the pure carrier in C-band to the satellite and receiving the pure carrier in the L-band on a spectrum analyzer. This study showed that the severe drop in C/N0 is not observed when the pure carrier is received. The C/N0 drop was within the limit that is expected for the L1 and L5 frequency, i.e. L5 more affected than L1 due to the lower L5 frequency. This test concluded that large drop in C/N0 for the BPSK modulated L5 signal may be due to the higher chipping rate for L5 signal i.e. 10MHz compared to the lower chipping rate of 1MHz for the L1 signal. Also there was a study required to know how the receiver processes the signals with different chipping rates and compute the carrier to noise ratio.

Equinox Effects on GPS signals

The occurrence of scintillation is found to be maximum in equinox months and minimum in summer months. Different levels of scintillation is observed in some months, but found that the weak scintillation ($0.2<S4\leq0.4$) is dominating throughout the period. The suppression or enhancement of pre-midnight scintillations during magnetic disturbed and quiet periods is found to be a seasonal and local time dependent factor. Pre-midnight and post midnight occurrence of scintillation is also reported in the low latitude regions during equinox. Pre-midnight scintillation was found to be maximum in equinox whereas it is minimum in winter months.

Disturbances in the ionosphere cause significant effects on satellite signals for communication and navigation, which are dependent on the signal frequency and the ionospheric electron content. The equatorial ionosphere is highly dynamical, unpredictable and is characterized by the existence of intense equatorial plasma bubble associated irregularities. These irregularities affect almost all radio communication systems utilizing the earth space propagation path. Also much of the current attention is directed towards understanding the cause and effect of equatorial ionospheric irregularities and their effects on satellite navigation systems. Ionospheric scintillations, the most significant manifestation of such disturbances, often takes place in equatorial region. Ionospheric scintillation is the most significant disturbance that can affect GPS users. Under normal circumstances, errors due to GPS signals travelling through the ionosphere can be modeled by measurement on two (or more) frequencies. However during periods of disturbance such as scintillations, this can be impractical and receiver performance can be severely degraded. The low latitude ionosphere poses a challenge to both GPS users and satellite based augmentation system providers. It occurs when the GPS satellite signal travels through small scale irregularities in electron density in the ionosphere, typically in the evening and nighttime in equatorial regions.

Effect of Scintillation on the GAGAN GEO signals

It was observed that at time 1600 to 1900UTC the L1 signal dropped by about 10dB. However, the effect on the L5 signal was more severe. The L5 signal dropped by about 30dB. The sudden drop in the signals caused instances of receiver loosing lock in the L5 and caused the system to malfunction. In order to understand this phenomenon, the following tasks were undertaken at the site:

1. **RF Noise survey during the time of signal drop:** The results of the RF noise survey conducted during the time of signal drop revealed that there is no external RF signal causing interference to the GEO signals and causing the loss of lock for the GPS receiver. The plots generated during the noise survey are shown in figures 3 and 4.

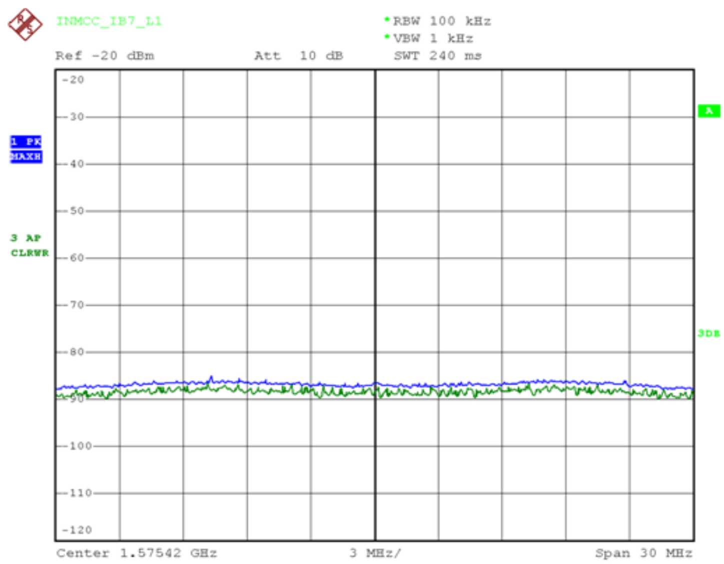

Figure 3: RF Noise Survey L1 Band

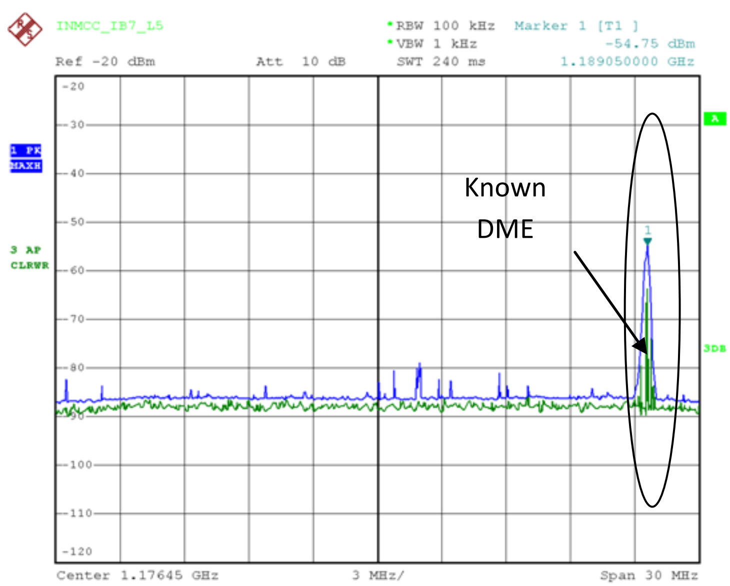

Figure 4: RF Noise Survey L5 Band

2. **Physical Observation of the C/N0 from the Receiver**: The physical observation of the phenomena revealed that after 1400UTC the C/N0 starts jumping and at the peak time of the activity at 1800UTC, the L5 signal showed a drop of 30dBbelow the nominal value, which caused the receiver to lose the lock on the GEO stationary satellite momentarily and affecting the performance of the GAGAN system. The C/N0 behavior observed during September / October 2011and March 2012 are shown in figures 5 to 10.

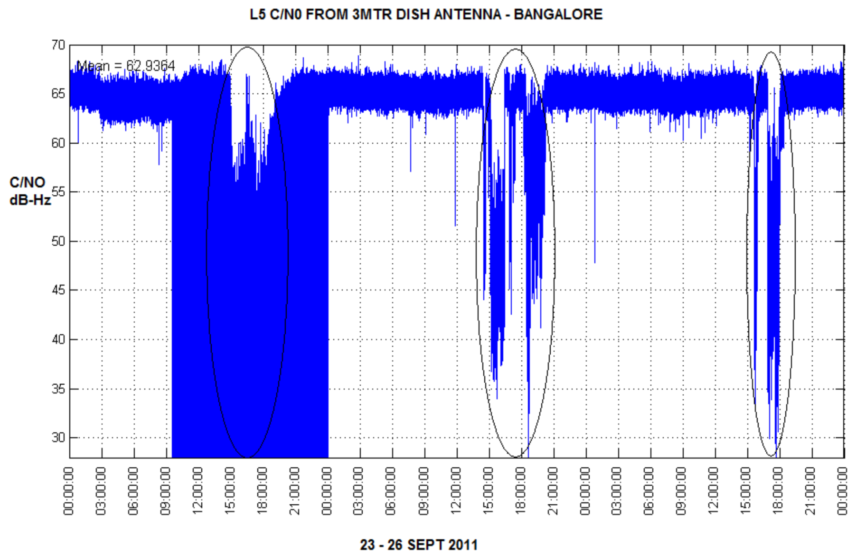

Figure 5: L5 C/N0 Variation Sept 2011

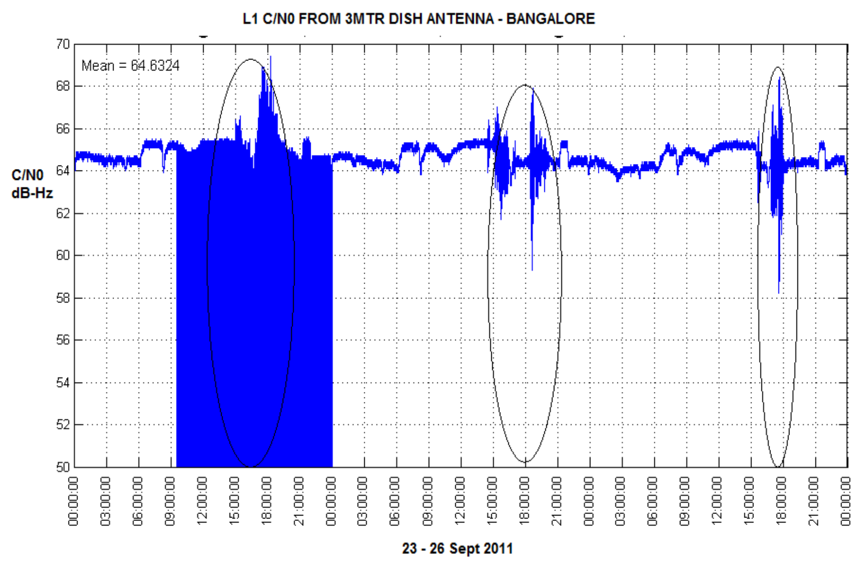

Figure 6: L1 C/N0 Variation Sept 2011

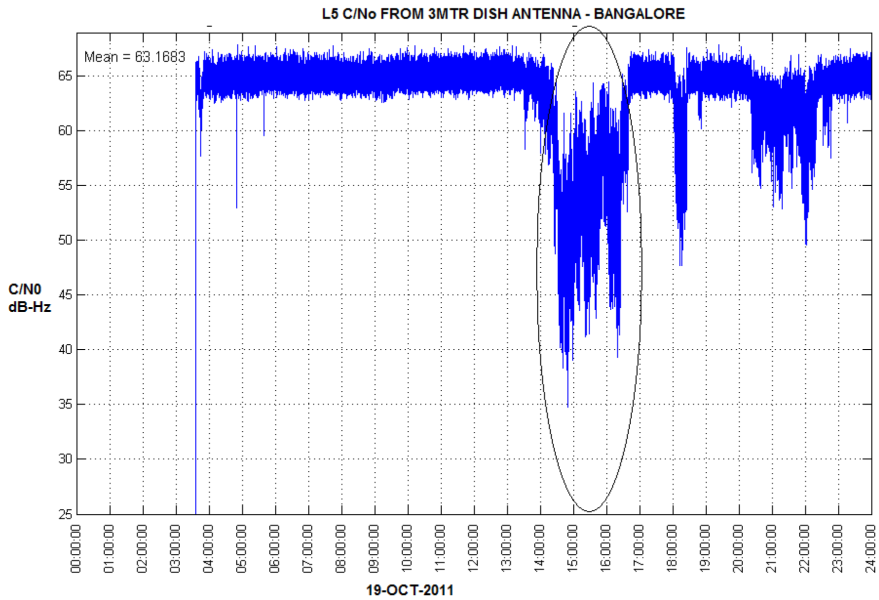

Figure 7: L5 C/N0 Variation Oct 2011

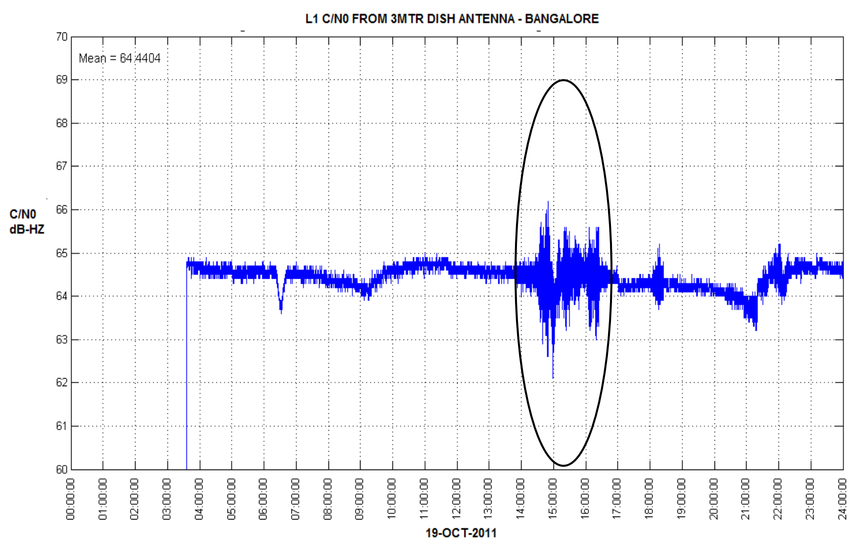

Figure 8: L1 C/N0 Variation Oct 2011

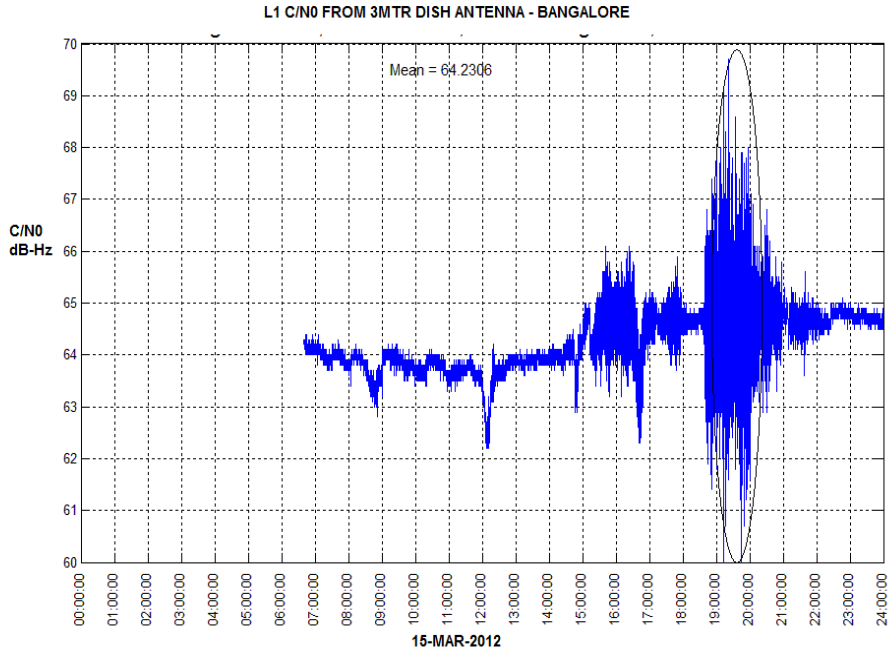

Figure 9: L1 C/N0 Variation Mar 2012

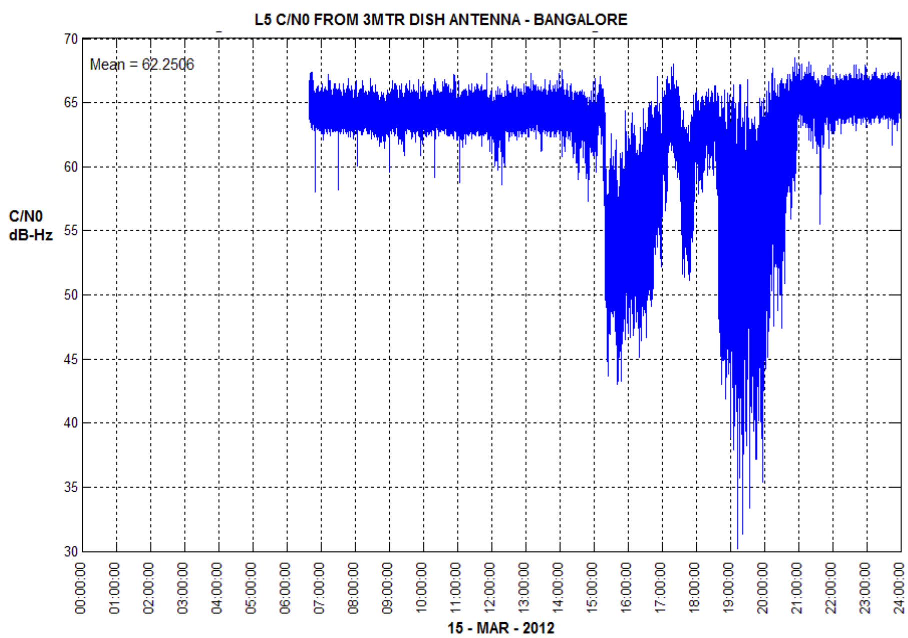

Figure 10: L5 C/N0 Variation Mar 2012

3. **Analysis of Measurement Data collected from Reference Stations**: This data analysis revealed that, the GPS and GEO measurement data from the reference stations at different locations in India were also affected by the scintillation. But the intensity varied depending on the geographic location of the station. Also the effect on the L5 signal could not be verified due to the fact that these reference stations are not equipped with receivers capable of receiving the L5 signals.

Since this was a first experience receiving the L5 frequency using a GPS receiver, lot of analysis were carried out to understand the exact cause of the problem. Also the difference on the affect on the L1 and L5 frequency was also studied in detail. But the classical theory of computing the effect of ionosphere on the L1 and L5 signals were not holding good as the affect on L5 signals were much higher than expected. Since always this effect was seen after midnight local time it was concluded that the cause of the problem could be the scintillation, which is a post dusk phenomena.

Study of Scintillation on pure carrier

The affect of scintillation on the modulated L1 and L5 signals could not be concluded due to the large impact it had on the L5 compared to the L1. It is always better to study the effect of ionosphere on pure carrier than the modulated and spread signals. This is because it will be inconclusive to analyze the results when the signal received is a modulated spread spectrum signals.

The setup used for studying the effect of scintillation on pure carrier is shown in Figure 11.

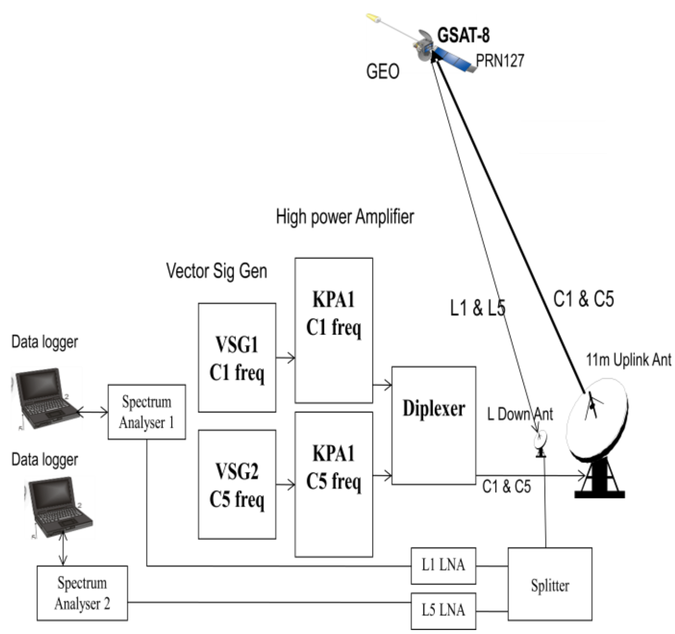

Figure 11: Set up for testing with pure carrier

Here the nominal up-link frequency signal (For both L1 and L5 frequency) in the extended C-band is uplinked to the Navigation payload (PRN127). The uplink signal is adjusted to drive the SSPA in the navigation payload to operate in saturation. The down-linked signals are received through a dish antenna and after proper amplification are monitored on two spectrum analyzers set for L1 and L5 frequency. The output of the spectrum analyzer is continuously recorded for post-offline analysis.

The plot of the C/N0 and the signal level observed during the period is given in the plots shown in Figures 12 and 13.

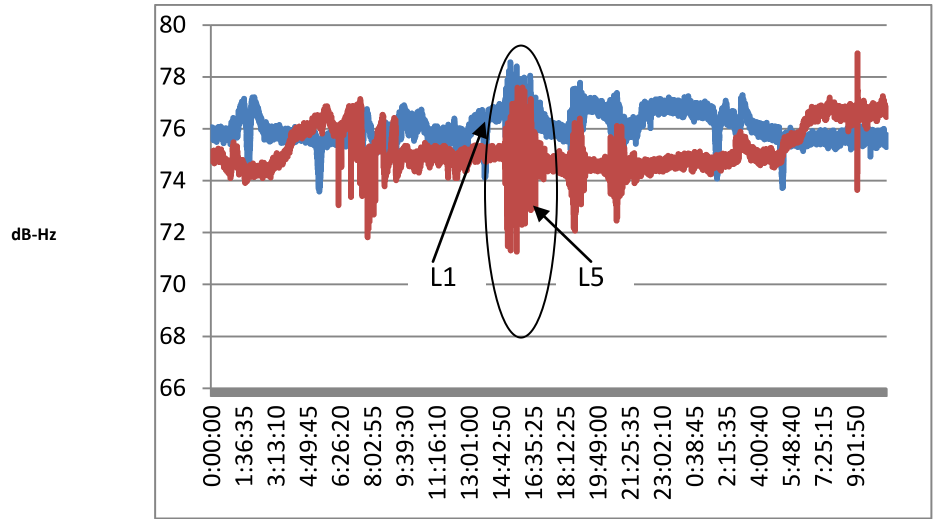

Figure 12: L1 & L5 C/N0 (dB-Hz)

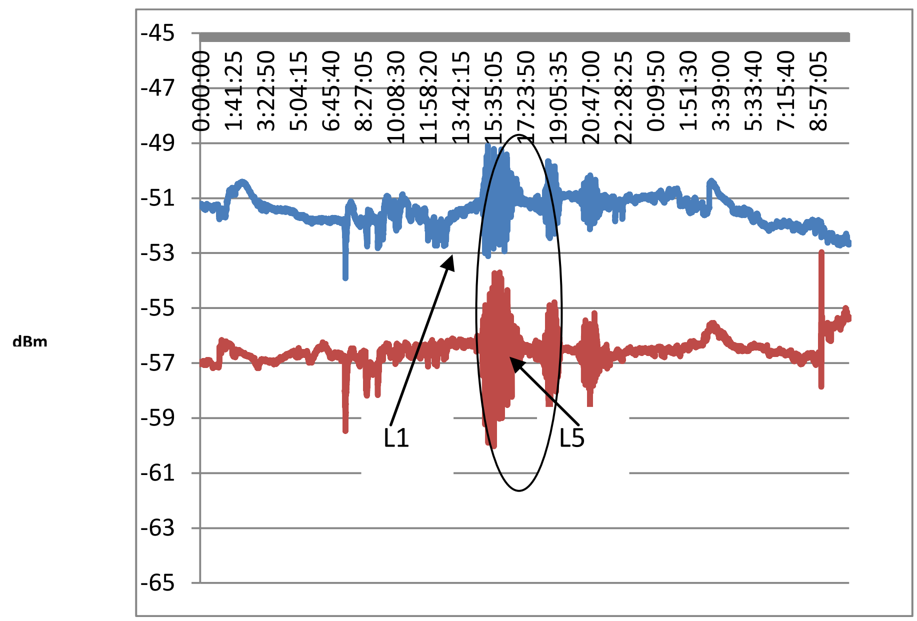

Figure 13: L1 & L5 Signal Level (dBm)

The analysis of the results shows that the effect of the scintillation on L1 and L5 carrier are as per the frequency difference in frequency between the L1 and L5. That is the higher frequency gets less affected and the lower frequency gets more affected due to the propagation through ionosphere. Also the drop in C/N0 is not as severe as it was when the carrier was modulated.

Hence the study concluded that the modulation and chipping rate plays very important role in this phenomena which is due to the scintillation. Also the effect is more predominant on L5 due to the higher chipping rate of 10MHz and less predominant due to the less chipping rate of 1MHz.

CONCLUSION

The following are the conclusion of the study conducted during the Geo integration of the GAGAN navigation payload with the uplink station:

1. The scintillation effect is predominant in the equatorial region and is post dusk phenomena.
2. The affect of scintillation on the L5 modulated carrier is very high compared that on the L1 modulated carrier.
3. The effect is comparable and obeying the theoretical results when pure carrier without modulation is used.
4. The effect is more predominant on modulated L5 due to the higher chipping rate of 10MHz and less predominant on modulated L1 due to the lower chipping rate of 1 MHz.

Based on this study the following actions have been initiated to fix the problem:

1. In order to operate an uplink station for SBAS in the equatorial region it will be required to reduce the threshold for unlock in the GPS receiver to such an extent to avoid loss of lock during the equinox. This is done after practically collecting the data and fixing the threshold after analysis.
2. The data has been provided to OEMs to study the problem and come out with a solution. Also certain software changes have been incorporated in the system to take care of this phenomenon.

After fixing the problem during the GEO integration which happened from August to December 2011 (equinox period), the system did not fault the system during the equinox in March-April 2012 and September-October 2012.

The system is always under observation and the data is collected and analyzed for any further issues. The system performed well during the Solar Flare which happened recently during the period 15-17 July 2012.