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Estimation of Differential Code Bias of IRNSS Satellites using Zero Mean Method

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***Abstract*--Indian Regional Navigation Satellite System (IRNSS) or Navigation with Indian Constellation (NavIC) has been developed and monitored by ISRO, India. IRNSS measurements are being affected by many residuals or biases. Differential Code Bias (DCB), is one of the main error sources to estimate the precise Total Electron Content (TEC) in the ionosphere. Differential delay biases of the dual-frequency band signals in both satellite and receiver are called satellite differential code biases (SDCBs) and receiver differential code biases (RDCBs). In this paper the combined satellite and receiver DCBs are measured. The DCB estimation of IRNSS signals is important for improving IRNSS user positioning accuracy in real-time applications.**

Index terms: Differential Code Bias (DCB), Total Electron Content (TEC), IRNSS or NavIC.

I. Introduction

In the last few decades, rapid growth has been reported in the satellite-based navigation system due to its widespread application. Various constellation and monitoring stations have been developed in global and regional fashion. Both global and regional navigation systems provide signals/observations on multiple frequencies (at least dual frequency), helpful for the monitoring of earth ionosphere. Total Electron Content (TEC) computed at the ionosphere using these observations can be used for better positioning and other scientific applications like monitoring, modeling, and prediction of the ionosphere, solar flare, geomagnetic storms and natural hazards (e.g. earthquakes, tsunamis, and volcanic eruptions). Thousands of GNSS monitoring stations have been established all across the world towards the precise estimation of TEC at the ionosphere [1]. Highly Precise TEC can be estimated using dual-frequency pseudo-range and carrier phase measurements.

Navigation with Indian Constellation (NavIC) is an autonomous regional satellite navigation system developed by the Indian Space Research Organisation (ISRO) which would be under the total control of the Indian government. It provides navigation services on two frequencies i.e. L5 (1176.45 ± 12 MHz) and S-band (2492.028 ± 8.25 MHz). It consist a constellation of 7 navigational satellites; 3 of the satellites are placed in the Geostationary orbit (GEO) and remaining 4 in Geosynchronous orbit(GSO) to have a larger signal footprint and lower number of satellites to map the region. It is designed to provide accurate position information service to users in India as well as the region extending up to 1500 km from its boundary, which is its primary service area [2].

This paper mainly focuses on the estimation of DCB for all available IRNSS satellites using the zero-mean method [3]. In this paper, the pseudo ranges measured on L5 and S-band frequencies are used to compute satellite and receiver DCB.

II. DCB Estimation Theory

Several methods for determining the DCB of satellites have been developed based on data from either global or regional ground stations [4]. In this paper for the calculation of DCB, we have applied a zero mean condition approach where it is assumed that mean of all satellite DCB, in the constellation, is zero.

$$\sum_{i=1}^{n} DCBSat(i) = 0$$

The following steps are designed for this processing.

The measurements of code delay and carrier phase at two L5 and S-band frequencies are included are considered. The code delay is defined as P1 and P2, and the corresponding carrier phase is defined as L1 and L2, where all quantities are defined in length unit. Geometry free combination on code delay is defined as P4 = P1 −P2, and on the carrier phase, it is defined as L4 = L1−L2, where all the measurements of code delay and carrier phase at two L5 and S-band frequencies are included in IRNSS data [5]. As it is well known, the precision of ionospheric TEC observable on the carrier phase is much higher (about two orders of magnitude) than that on code delay, but they are affected by the potential ambiguity.

To retain the high precision and eliminate the impact of ambiguity in the carrier-phase ionospheric observable, a common technique named "carrier leveling of code phases" or "carrier smoothing filter", called Hatch filter is applied during the individual continuous arc, and the processed ionospheric observable including two parts, the ionospheric TEC and the DCB of the satellite plus receiver [6].

The pseudo-range and carrier phase measurements of the IRNSS receiver may be represented as:

$$P_1 = P_0 + {}^{1}/_{f_1^2} + T + c(dt_r - dt_s) + D_1^r + D_1^s + \epsilon_p^1 \quad \text{--------(1)}$$

$$P_2 = P_0 + {}^{1}/_{f_2^2} + T + c(dt_r - dt_s) + D_2^r + D_2^s + \epsilon_p^2 \quad \text{--------(2)}$$

$$L_1 = P_0 - {}^{1}/_{f_1^2} + T + c(dt_r - dt_s) + \lambda_1(N_1 + \alpha_1^r + \alpha_1^s) + \epsilon_\varphi^1 \quad \text{--------(3)}$$

$$L_2 = P_0 - {}^{1}/_{f_2^2} + T + c(dt_r - dt_s) + \lambda_2(N_1 + \alpha_2^r + \alpha_2^s) + \epsilon_\varphi^2 \quad \text{--------(4)}$$

Here subscript 1 is for S-band carrier frequency (2492.028 MHz) and 2 for L5 band carrier frequency (1176.45 MHz). Where 'P' is a pseudo-range measurement, 'L' is carrier phase measurements recorded by reference receiver, 'Po' is a geometric range between receiver and satellite, 'I' stands for Ionospheric delay,'T' is a tropospheric delay, '∂tr' is receiver clock bias, '∂ts' is satellite clock bias, 'Dr' is code delay in the receiver, 'Ds' is code delay in satellite, 'N' is the ambiguity of carrier phase, 'αc' and 'αr' is phase delay because of satellite and receiver hardware [7], 'ϵ' stands for the receiver and multipath noise. 'f' represents the carrier phase frequency.

The geometric free combination of pseudo-range measurement may be computed as follows.

$$P_4 = P_1 - P_2$$
$$= I\,({}^{1}/_{f_1^2} - {}^{1}/_{f_2^2}) + DCBs + DCBr$$
$$P_4 = P_1 - P_2 = I\,({}^{1}/_{f_1^2} - {}^{1}/_{f_2^2}) + SPR \quad \text{---------(5)}$$

Where, DCBs=D_1^s-D_2^s, DCBr=D_1^r-D_2^r and SPR is satellite plus receiver differential bias.

SPR= DCBs + DCBr.

Similarly for Carrier Phase measurement:

$$L_4 = L_1 - L_2 = -I({}^{1}/_{f_1^2} - {}^{1}/_{f_2^2}) + (\lambda_1 N_1 - \lambda_2 N_2) + (\lambda_1 \alpha_1^r - \lambda_2 \alpha_2^r) + (\lambda_1 \alpha_1^s - \lambda_2 \alpha_2^s)$$

Here as we know that pseudo-range difference P_4 is noisier than carrier phase measurements.

The P_4 measurements were smoothed with L_4 measurements using the carrier-smoothing filter called the Hatch filter.

The equation for finding STEC follows as:

$$STEC1 = \frac{1}{40.3}\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}(P_1 - P_2) \quad \text{----------- step -1}$$

In step-1 STEC we are obtaining absolute STEC also with DCB. So we are calculating our DCB with the subtraction of STEC and absolute STEC.

Ionospheric delay in IRNSS signal may be computed by first-order Ionospheric refraction, as higher orders have a minor effect on ionospheric delay. The Ionospheric delay can be expressed as follows:

$$I = \frac{40.3}{f^2}\, STEC$$

After smoothing pseudo-range difference in equation (5), I (Ionospheric Delay), may be represented by Slant TEC (STEC) as follows:

$$P_4 = 40.3({}^{1}/_{f_1^2} - {}^{1}/_{f_2^2})STEC + DCBs + DCBr$$

$$P_4 = 40.3({}^{1}/_{f_1^2} - {}^{1}/_{f_2^2})\ STEC + SPR\ (DCB)$$

$$DCB\ (SPR) = P_4 - 40.3\ ({}^{1}/_{f_1^2} - {}^{1}/_{f_2^2})\ STEC$$

From the above equation, we are calculating the STEC is known as absolute STEC and represented as STEC2 [8]. It is calculated as by equating DCB of satellite plus receiver (SPR) is equals to zero. This is the ZERO mean method we are using in this project to find out our DCB.

$$\sum_{i=1}^{n} DCBSat(i) = 0$$

The absolute STEC equation is followed as:

$$STEC2 = \frac{P4}{40.3\ \left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)} \quad \text{----------- step-2}$$

We are obtaining the DCB, the subtraction STEC2 from STEC1.

$$DCB = STEC2 - STEC1$$

We are dividing our resultant DCB with the velocity of light (V) to obtain DCB in nano sec.

$$DCB = \frac{DCB}{V}$$

The resultant DCB are divided with 1TECU = 10^{16}

$$DCB = \frac{DCB}{10^{16}}$$

The final DCB error, we are obtaining from the above equation at the time radio-wave transmitter and receivers.

III. Results

As discussed, the DCB noise in TEC can be observed with six different satellites. IRNSS Constellations consists of seven satellites out of them only six satellites are available while observing. These six satellite DCB results are shown in the below figures.

These figures represent the DCB variation of six satellites in nano sec with respect to the time. These DCB values range up to 24 hours a day. These DCB value effects on total Total Electron Content (TEC) value at the transmission of data from the satellite to the ground receiver. It is observed that the DCB range is 2.5 nano sec to 5.7 nano sec.

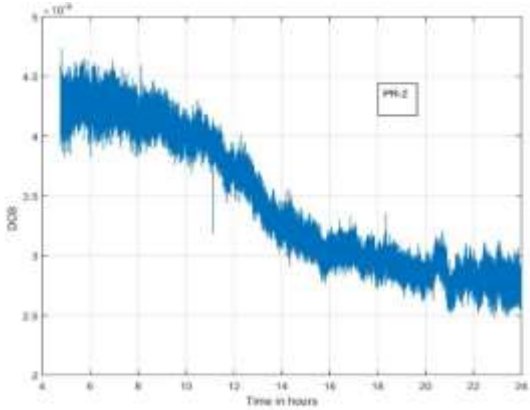

Fig: 1 DCB vs Time plot for 2nd satellite

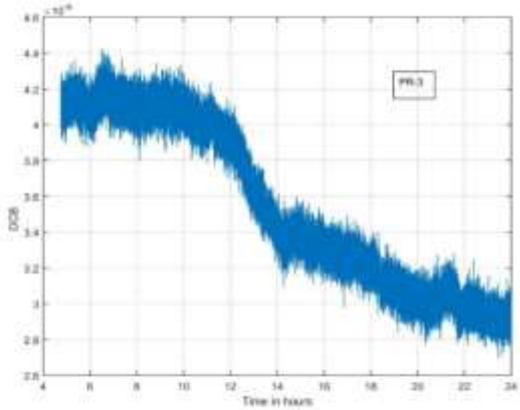

Fig: 2 DCB vs Time plot for 3rd satellite

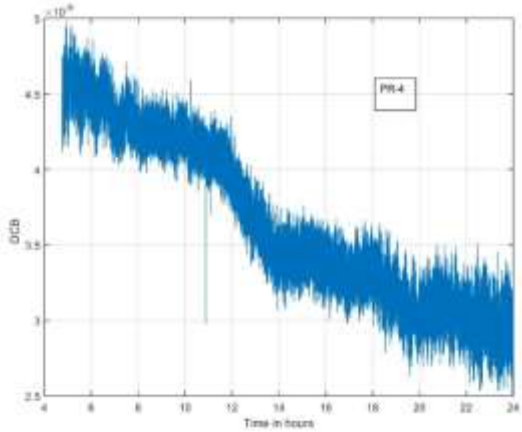

Fig: 3 DCB vs Time plot for 4th satellite

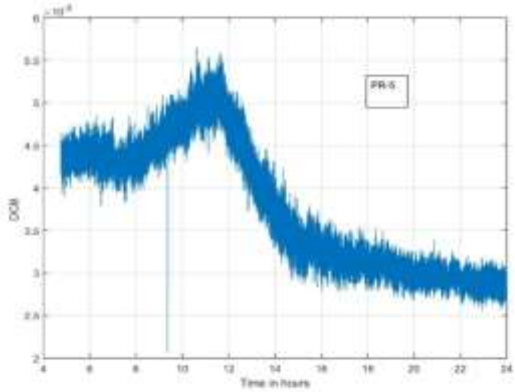

Fig: 4 DCB vs Time plot for 5th satellite

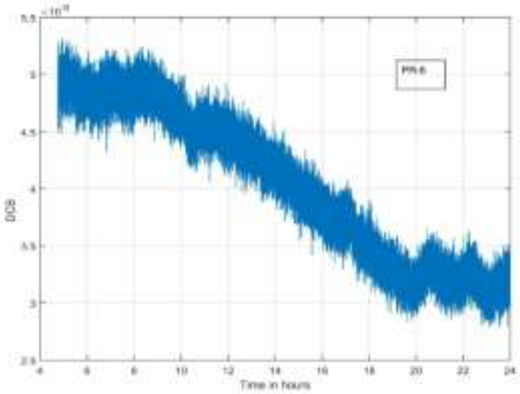

Fig: 5 DCB vs Time plot for 6th satellite

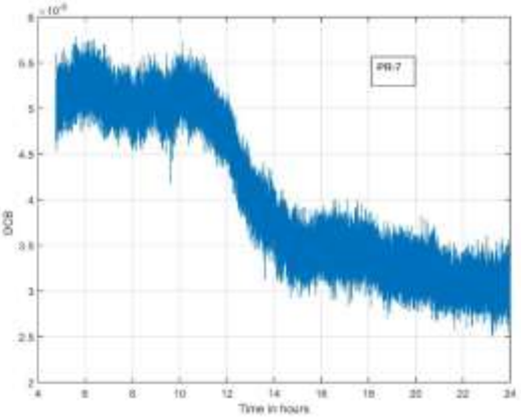

Fig: 6 DCB vs Time plot for 7th satellite

IV. Conclusion

We have estimated the DCB for IRNSS, then used zero mean conditions for separating the DCB of the Satellite and receiver. Further, the stability of computed DCB may be improved by using the observation of a high elevation angle from multiple receiver stations. Further, this work can be extended to the data of greater number of tracking stations. IRNSS signal may be helpful for the precise estimation of ionospheres along with the other GNSS measurements.

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