論文

GNSS 신호감시국용 GPS/갈릴레오 복합수신기 성능시험결과

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Performance Test Results of GPS/Galileo Combined Receiver for GNSS Sensor Station

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초록

본 논문은 위성항법신호감시국용 GPS/갈릴레오 복합수신기에 대한 구현 및 성능 시험결과를 기술한 논문으로 복합수신기는 단일 플랫폼에서 갈릴레오 E1, E5a 신호와 GPS L1, L2C, L5 신호를 수신처리 할 수 있으며, GPS신호와 갈릴레오 E1 신호를 복합적으로 처리함으로써, 위치정확도가 향상됨을 보였다. 각 신호에 대한 신호획득을 신속하게 하기 위해, 모든 신호에 대해 정합필터와 FFT 방식이 결합된 방식을 적용하였고, 신호추적과정에서는 다수의 추적루프를 적용하였으며 본 논문에서는 주요 신호에 대한 신호획득 및 추적과정의 시험결과를 보였다. 또한 기존에 발표된 논문과의 차별화 항목으로, 항법신호의 수신레벨이 낮아 CW 형태와 같은 간섭신호에도 영향을 받는바, 이에 대한 개발된 항재밍 모듈에 대한 시험결과도 제시하였으며, 성능측면에서의 비교를 위해 상용수신기와 개발된 수신기와의 성능 비교 결과도 함께 제시하였다.

Key Words : GPS/Galileo Receiver(복합수신기), GNSS Sensor Station(신호감시국), Navigation Signal Processing(항법신호처리), Signal Acquisition and Tracking(신호획득 및 추적).

1. Introduction

Global Navigation Satellite System has become a necessity tool for navigation and positioning in both civilian and military field and applications[1]. Global Positioning System (GPS) is a satellite-based navigation system. It is based on the computation of range from the receiver to multiple satellites by multiplying the time delay that a GPS signal needs to travel from the satellites to the receiver by velocity of light. GPS has already been used widely both in civilian and military community for positioning, navigation, timing and other position related applications[2][3]. The system has already proved it's reliability, availability and good accuracy for many applications. Due to this nature, in future, other countries like Europe are going to launch new satellite-based navigation system called Galileo[4].

Also, China will be completed the COMPASS for global navigation system which consists of 35 satellites where already launched by six satellites[5]. There is also a proposal to launch Quasi Zenith Satellite System for navigation in Japan. JAPAN is already launch one satellite among three satellites for testing and acquiring the space proven of satellite equipments[6]. Considering the foreign situation, we are going to the development GPS and Galileo combined signal processing receiver unit. In case of using the combination of GPS and Galileo navigation signal processing, it will be enhanced the availability and accuracy performance. In this

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paper it will be proven that the testing result based on real signal processing board is to verify the GPS and Galileo combination processing probability. The GPS/Galileo combined receiver has a RF/IF converter board, signal splitter board, control board, and four(4) signal board such as GPS L1/Galileo E1 signal board, GPS L2C board, GPS L5 board and Galileo E5a board. Each baseband signal processing board has dual FPGA and single DSP. Especially, to enhance the signal sensitivity of acquisition and tracking phase, we propose the new algorithm and test result by manufacturing the hardware platform. During the implementation process, we find that unlike the FPGA, DSP processor cannot handle parallel task at the same time and can process only one task at a time. Therefore, task scheduling of DSP is an important factor in real condition which several satellite signals must be processed at the same time. When the real signal is processed in hardware receiver, the hardware receiver can work well as software receiver if the number of channels is little.

2. Receiver Implementation

2.1 RF/IF module

The GPS/Galileo combined receiver is designed for high precision Galileo Sensor Station. The signal processing supports complete GPS L1, L2C, L5 and Galileo E1/E5a signal tracking. The RF front-end consist of Antenna and RF/IF converter module. The configuration and test result of wideband antenna module which can receive the frequency from 1.1 GHz to 1.6 GHz. There are three RF/IF converter function inside the RF/IF converter. To make the compact of RF/IF converter module, three RF/IF conversion module are implemented in single box as can be seen in Fig. 1. Due to manufacture the single board, the installation is more simple and combined GPS and Galileo receiver can possible to integrate in the single unit.[7]

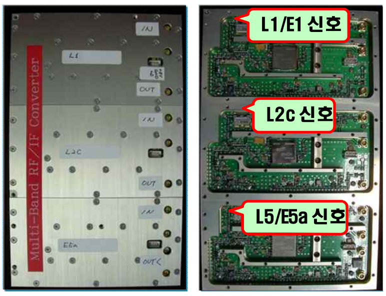


Fig. 1 Product of RF/IF converter module

Input signal of RF/IF converter module is transmitted from the prototyping antenna with wideband LNA. Before manufacturing the final RF/IF converter module, we make the prototype module for previously functional testing purpose of RF/IF module to reduce the development risk. The test results of RF-IF converter module are shown in Fig. 2. As shown in Fig. 2 it is possible to find that the RF/IF signal is appeared at L1, L2C, L5 for GPS and Galileo E5a frequencies each other.[8]

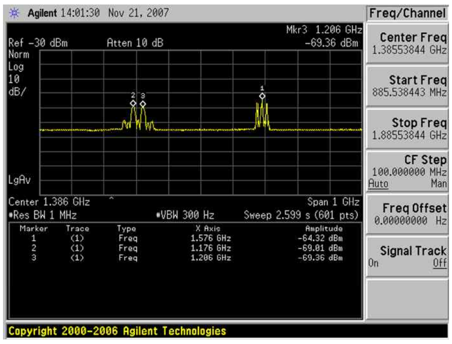


Fig. 2. Performance of RF/IF prototype product

2.2 Baseband signal processing module

The input of baseband signal processing module come from A/D converter module which can be processing 8 bit quantization level and is installed in each baseband board. The sample time of each sample depend on the sampling frequency. As our case, the sample time becomes about 9ns according to the sampling frequency of 112.53 MHz. It becomes about 2.664 m if sample time is changed into a distance. Since the GNSS signal and digitize clock of the receiver cannot be synchronized, it is not likely to match a data point with true beginning of the C/A code. Under the worst condition, the beginning point of the C/A code can be about 4.5 ns away from the true value, when the true beginning of the C/A code falls at the middle of two digitize points. Therefore, the maximum distance error at the receiver according to the sampling frequency is about 1.332 m. The detailed configuration of baseband is described in Fig 3.[7]

The baseband function module is to process the signal acquisition, tracking function needed to extract the navigation solution[9].

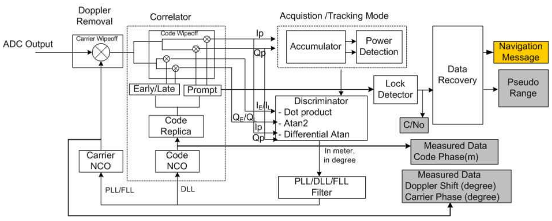


Fig.3 Functional Block of Baseband signal processing

The mission of signal acquisition is to seek the visible satellite and determine the coarse values of carrier frequency and code phase about visible satellites. Code phase is the time alignment between the PRN code of incoming signal and a locally generated PRN code which generate by using time information transmitted from atomic clock unit[10]. The acquisition result for GPS L1 signal which related with PRN 6 is shown in Fig. 4. The acquisition result shows code phase and Doppler frequency under input signal with -142 dBm. To determine the acquisition completion the threshold ratio between first peak and second peak is used over value about 2 times.[8]

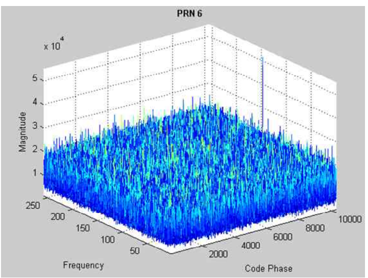


Fig. 4 Signal acquisition result(@ -142 dBm)

To acquire the signal in weak input signal condition, the matched filter plus FFT algorithm are applied. At that time matched filter with 256 tap point, size of FFT with 256, and Non-coherent integration time with 150 times are applied. The processing time to get the signal acquisition takes about 790 second. To verify if the acquisition function is working we use the tracking result as shown Fig. 5.

The tracking loop use to find more exactly code phase and carrier phase than acquisition phase. The tracking loops consist of a delay lock loop (DLL) for tracking the code and a phase lock loop (PLL) to track the carrier.

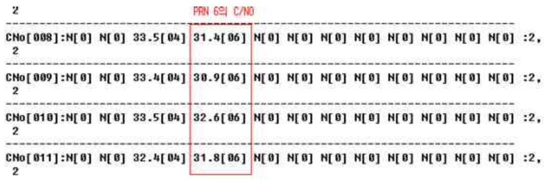


Fig. 5 Signal tracking result(@ -142 dBm)

The code tracking block of the receiver is implemented using the method of Early-Late code tracking, that involves correlation with three different generated codes known as the early (E), the prompt (P), and the late (L) codes. The input of code generator is computed through normalized early minus late envelope discriminator. The carrier tracking block of the receiver is implemented as a Costas PLL. A PLL measures the carrier phase error and adjusts the frequency of the local oscillator based on that error. The input of local oscillator is computed through arctangent discriminator because of its high accuracy and insensitivity towards navigation bit transitions. In order to improve tracking sensitivity, SNR and noise bandwidth is handled. The SNR can rise by longer integration time and noise bandwidth is reduced according to noise power in weak signal as the adaptive bandwidth algorithm. As a test results of weak signal condition, the operation of L2C signal tracking for each PRN can be proven by display the C/No values as shown in Fig. 6

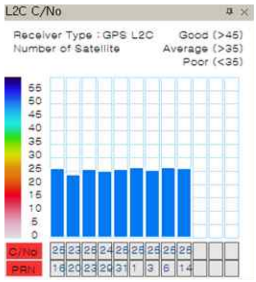


Fig. 6 Tracking performance(@ -152 dBm)

As another tracking result, error performance of carrier phase is shown in Fig. 7.

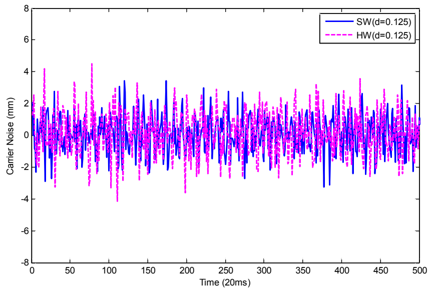


Fig. 7 Test result of carrier phase error for L2C

In Fig. 7, red color line means the test result on hardware and blue color line means the test result on software.

3. Performance Verification of Receiver

3.1 Function Test Result

Combined the GPS and Galileo system could be provide the high availability instead of GPS or Galileo only. Because it could be used more satellite than single system within the sky window to calculate the positioning information system availability will be increased. GPS and Galileo Combined receiver unit can be concurrently processing up to 27ch which consists of 12 channels for GPS and 15 channels for Galileo. To verify the functional operation of GPS and Galileo combined receiver unit, it will be used the GPS and Galileo Signal simulator which can be manufactured by SPIRENT company. To verify the receiver function, it will be described the Galileo multichannel processing results. As shown in Fig. 8, the results of 15 channels processing for Galileo signal are displayed which is captured data in processing user interface window. we knows that multi-channel signal processing functions are normally working as we can expected.

3.2 Performance Test Result

This section shows the positioning accuracy as comparison result between commercial receiver(Model:PWRPAK-II-STD)manufactured by Novatel and ETRI developing receiver. As a performance comparison parameters, horizontal and vertical accuracy are shown in table 1. At that time it would be applied that two types signal such as live signal and signal generated by RF simulator for GPS L1 band. From the table 1, we can find that the performance of ETRI product is similar to performance of commercial product as shown in table 1.

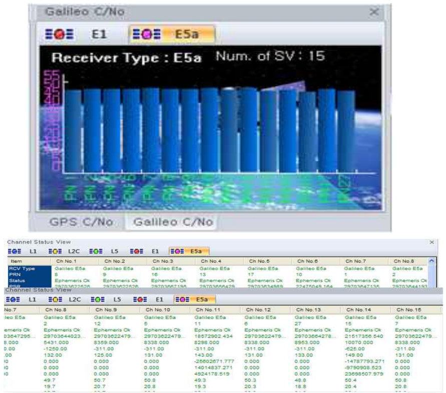


Fig. 8 Processing results for Galileo signals

Table 1. Accuracy test results

GPS L1(Live)	Horizontal Accuracy[m]	Vertical Accuracy[m]
ETRI Receiver	0.92	1.23
Commercial Receiver	1.26	1.26

The combination result of GPS L1 and Galileo E1 signal processing is displayed in Fig.9. The GPS L1 signal processing result is displayed by red color and green color mean the Galileo E1 signal processing result. In Fig.11, blue color mean the GPS L1 and Galileo E1 combination processing result. Accuracy of horizontal and vertical are shown upper and lower in UI left side window. The performance of combination is displayed in Table 2. It can proven that the performance of Galileo E1 signal is better performance than GPS L1 signal.

Table 2. Accuracy test results of signal combination

RF Simulator Signal	Horizontal Accuracy[m]	Vertical Accuracy[m]
GPS L1	0.63	1.12
Galileo E1	0.25	0.37
Combination	0.35	0.54

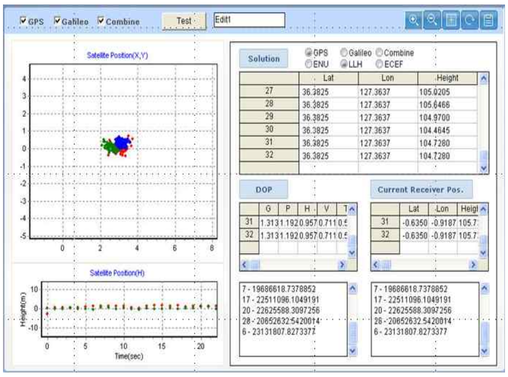


Fig. 9 GPS L1 and Galileo E1 Combination result

From the test results we find that combination of GPS L1 and Galileo E1 is better performance than each signal processing.

3.3 Anti-jamming test result

The susceptibility of the GPS signals to interference is of concern to the GPS user community[11]. Because of the low received power of the GPS signals, outages can easily occur due to unintentional interference, and the potential exists to deny access to the GPS signals using easily obtainable RF hardware. As a developing results, we presents the test result by using the module processing of the anti-jamming function at RF level. The test environment for anti-jamming module described in Fig. 10.

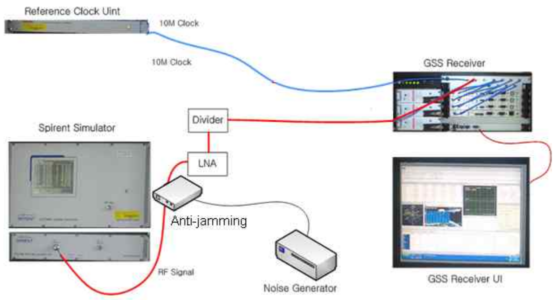
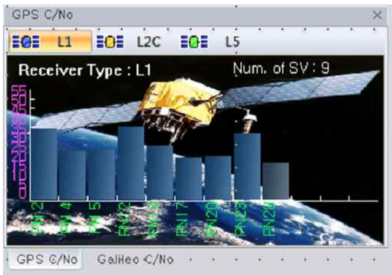
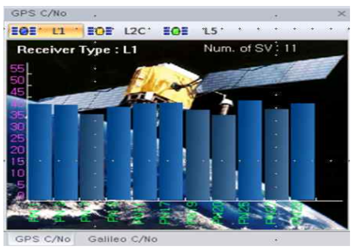


Fig. 10 Test environment of Anti-jamming module

The anti-jamming module can measure the phase between received interference signal and internally generated signal with time difference use to mitigate the interference. We can correctly know the phase value for generated signal. To do functional test of the anti-jamming module, the level of interference is applied by order. As a first phase, interference level is applied with 30 dB by signal generator and then checks if receiver is continuously tracking the signal. Next step, interference signal level is increased by 50 dB. Finally interference test level is increased up to 75 dB. we find that according to interference level, channel number of signal tracking is changed and also confirm that the module is able to cover up to 70 dB of CW jamming signal as shown in Fig. 11.



(a) Channel Status after CW with 30 dB input



(b) Status after anti-jamming module connection

(c) Channel Status after CW with 70 dB input

Fig. 11 Test result of Anti-jamming module

4. Conclusions

This paper presents the test results of the GPS and Galileo combined receiver based on FPGA and DSP components on board. Also this paper show that normal operation for navigation receiver unit which consists of GPS signal processing function and Galileo signal processing function can be worked. To reduce the time necessary to get the signal acquisition it is used to combination scheme such as matched filter plus FFT algorithm. Also, in this paper, we presented algorithm optimization for performance of combined L1/E1 board. The application of extended integration algorithm in L1 signal can be compared with E1 receiver. In addition, it would be demonstrated that the performance of combined L1/E1 board in weak signal is meet the requirement for acquisition sensitivity, tracking sensitivity, and tracking accuracy. The different of previous paper is that this paper present test result of the anti-jamming functional module which is just prototype. Expecially to justify the anti-jamming performance, we presents the comparison performance using development receiver and commercial receiver.

ACKNOWLEDGMENT

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