Design and Analysis of High Dynamic CAPS Signal Simulation Testing System

Ma Hong-Jiao*,+, Hu Yong-Hui*, Wu Jian-Feng*,+, Huang Fei-Jiang*,+, Zhang Hong*
*National Time Service Center, Chinese Academy of Sciences, Lintong, Xi'an, Shaanxi, China
+Graduate University of Chinese Academy of Sciences, Beijing, China

***Abstract*—High dynamic China Area Positioning System signal simulation testing system are constructed by a space vehicle moving simulation system, CAPS signal simulator, CAPS base station, CAPS mobile station and Simulation control computer. Space vehicle moving simulation system generates static or dynamic position information, then send data to CAPS signal simulator through Ethernet. CAPS simulator produces navigation signal through the space vehicle position information. CAPS base station and mobile station can receive both CAPS satellite signal and CAPS simulator signal. CAPS base station transmits wireless difference data to CAPS mobile station in real time. This system has function of navigating, positioning, timing and speed measurement. The results from experiment show that bias of mean of longitude, latitude and altitude are 0.2632m, 0.6080m and 0.2318m respectively; bias of mean of speed is 0.0764m/s, variance is 0.2195 when the space vehicle is moving in 300m/s, but they are 0.2004m/s and 0.15094 respectively when in 500m/s.**

I. INTRODUCTION

China Area Positioning System (CAPS) is a new kind of navigation system based on satellite repeater communications. The constellation of CAPS rents 4 telecommunication satellites located in 87.5° E, 110.5° E, 134° E and 142° E [1], via using signal repeater in the satellite to transmit the message of time, parameters of satellite orbit and other navigation message produced by surface control station. Navigation and position time signal needed is sent out by atomic clock in surface control station [2]. Because of atomic clock in surface control station keeping quite high precision and stabilization, it decreases the technique difficulty of CAPS satellite navigation system; moreover, improves the precision of navigation.

12 Channel CAPS simulator has the basic function of simulating constellation of all visible CAPS satellite, motion state of CAPS satellite and customer receiver, generating fully capable CAPS satellite signals in real time, testing positioning accuracy, start-up time, signal receiver sensitivity of CAPS terminal. And when user's receiver in the stationary state, by changing the signal parameters to simulate navigation positioning performance when test user receiver carriers (such as vehicles, pedestrians, vehicles etc.) move under the CAPS track by changing the signal parameters.

Supported by West Light Foundation and Young Fund of The Chinese Academy of Sciences.

II. SYSTEM ARCHITECTURE INTRODUCTION

CAPS signal simulator has low, medium, high-dynamic test coexistence functions. CAPS signal simulator testing system can be used for simulation of various moving carrier based on CAPS carrier. It consists of CAPS signal simulator, CAPS mobile station, CAPS base station and flight simulator system. The linking frames of the system are sketched in Figure 1. The carrier moving simulation system accomplishes the design of the movement model with the aid of Matlab Simulink, and produces static or dynamic location information, and sends it to CAPS simulator via network interface of embedded Real-Time operating system VxWorks.

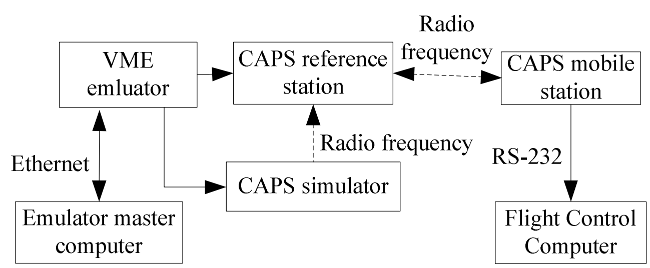

Figure 1. High Dynamic CAPS Signal Simulation Testing System

CAPS simulator consists of the time and frequency reference systems, computer systems, CAPS signal generator module, the RF up-converter module and network switches, the frames of which appear in Fig.2. Time and Frequency system, as reference frequency source, provides stable and reliable 10MHz frequency standard and 1pps signal.

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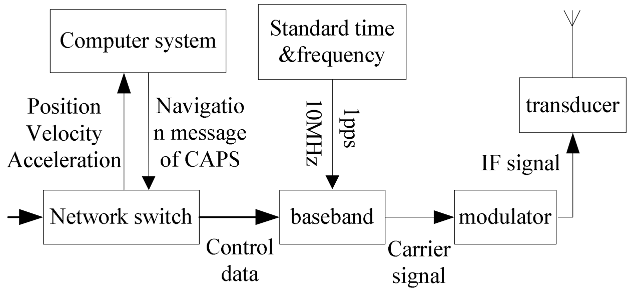

Figure 2. CAPS simulator structure

Computer system generates navigation signals by receiving carrier position, velocity and acceleration information from emulator master computer, and then transmits the navigation messages and control variable to baseband through network switch. Baseband sends carrier signals to up-transducer through modulator. The transducer sends out CAPS simulation signals through Antenna.

CAPS base station and mobile station can receive both CAPS satellite signal and CAPS simulator signal. CAPS base station transmits wireless difference data to CAPS mobile station in real time. This system has function of navigating, positioning, timing and speed measurement.

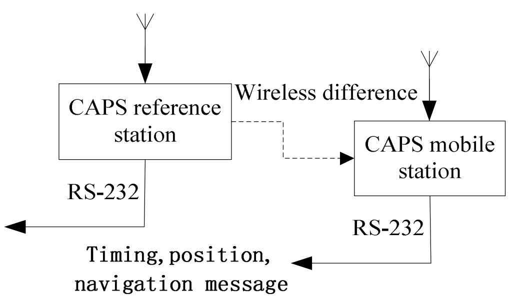

Figure 3. CAPS simulator receive unit

III. SYSTEM KEY TECHNOLOGY

A. Satellite ephemeris

Satellite ephemeris can be got directly from the orbit that the user sets up, the use of interpolation or extrapolation arrive at the valid data of simulation time It is not required that the users connect constellation document data with simulation time. By comparing all CAPS satellite X, Y, Z changes in 7 days from 00:00:00 on September 25, 2008 to 00:00:00 on October 2rd, 2008, we can approximately think that the position of satellite is a periodic change signal, with the period of 24 hours.

B. Doppler Frequency

Doppler frequency-shift occurs due to the changes of radial distance between the receiver and satellite. In pre-condition of knowing the speed in x, y and z three directions of the receiver, one calculates the radial velocity according to the relative position between the satellite and receiver, the description of the method is as following [4]: firstly calculate the direction cosine

$$\cos X_{i,j} = (X_{sat,i,j} - X_{rec,i,j}) / \rho_{i,j}\,,$$

$$\cos Y_{i,j} = (Y_{sat,i,j} - Y_{rec,i,j}) / \rho_{i,j}\,,$$

$$\cos Z_{i,j} = (Z_{sat,i,j} - Z_{rec,i,j}) / \rho_{i,j}\,, \text{ therein}$$

$$\rho_{i,j} = \sqrt{(X_{sat,i,j} - X_{rec,j})^2 + (Y_{sat,i,j} - Y_{rec,j})^2 + (Z_{sat,i,j} - Z_{rec,j})^2}$$

In derivation of the relative radial velocity of the receiver:

$$Vel_{i,j} = \cos X_{i,j} * vel\_x_{i,j} + \cos Y_{i,j} * vel\_y_{i,j} + \cos Z_{i,j} * vel\_z_{i,j} \tag{1}$$

The corresponding Doppler frequency of satellite i in time j can be got according to radial velocity:

$$f_{doppler,i,j} = \frac{Vel_{i,j} \cdot L_1}{C} \tag{2}$$

Where, L_1 is the frequency of carrier wave radio frequency, C is velocity of light.

The corresponding Doppler frequency change rate of satellite i in time j can be got according radial velocity

$$V_{doppler,i,j} = \frac{a_{i,j} \cdot L_1}{C} \tag{3}$$

Doppler frequency can affect code frequency, the formula:

$$f_{CA,doppler,i,j} = \frac{f_{doppler,i,j} \cdot f_{CA}}{L_1} \tag{4}$$

Where, f_{CA} is Pseudo Code frequency, namely, no Doppler offset.

C. Code DCO control words

The control of Code DCO is classified as frequency control and phase control. As a consequence of formula (4), we can get code frequency of Doppler frequency as following:

$$f_{code} = \frac{f_{CA} \times (L_1 + f_{doppler,i,j})}{L_1} \tag{5}$$

Where, L_1 is carrier wave frequency, f_{CA} is standard frequency of pseudo code, namely excluding Doppler frequency offset, f_{code} is code frequency including Doppler frequency offset, $f_{code} = f_{CA} + f_{CA,doppler,i,j}$, corresponding DCO frequency control words.

$$\Delta\phi_w(n) = \frac{f_{code} \cdot 2^N}{f_{clk}} \tag{6}$$

N is bit of code DCO accumulator.

Code DCO output frequency resolution: $f_{\min} = f_{clk} \cdot \frac{1}{2^N}$, resolution of phase accumulator is $\Delta\phi_{\min} = \frac{1}{2^N} chips$

If code DCO initial phase is ϕ_{w0} , then the calculation expression of initial phase control word is

$$\phi_{w0}(n) = \phi_{w0} \cdot \frac{2^N}{2\pi} \tag{7}$$

In the control of code DCO phase, to avoid jump of phase, only phase can be controlled for once.

D. Carrier DCO control words

Like code DCO, carrier DCO is obtained by Direct Digital Frequency Synthesis method. Sine- and cosine-mapping table are established under the control of carrier DCO. In accordance with the amplitude value corresponding to phase signal at sampling time the wave signal required is generated. Frequency of required signal is controlled by way of the change of wave form phase at two adjacent sampling times. Wave form phase $\phi_W(n)$ is got by accumulation of increment $\Delta\phi_W(n)$ of wave form phase, the larger $\Delta\phi_W(n)$ is, the larger carrier wave increasing rate becomes, and the higher frequency of carrier wave becomes.

N is digital number of phase accumulator, and also is digital number y of frequency control word. M is digit number of data that phase accumulator exports to sine- and cosine-mapping table, $M \le N$. K is digit number of the data output from sine-, cosine- mapping table of carrier DCO. To achieve frequency control, binary system is needed to represent phase. Suppose increment of unit vector is $\pi / 2^{N-1}$, frequency control word is $\Delta\phi_W(n)$, in this case the actual increment phase $\Delta\phi_W$ is

$$\Delta\phi_W = \Delta\phi_W(n) \cdot \frac{\pi}{2^{N-1}} \tag{8}$$

Carrier frequency is f, sampling period is T_{clk}, sampling frequency is f_{clk}, then

$$f = f_{clk} \cdot \frac{\Delta\phi_w}{2\pi} \tag{9}$$

Take formula (8) into formula (9)

$$f = f_{clk} \cdot \frac{\Delta\phi_w(n)}{2^N} \tag{10}$$

Then carrier DCO frequency control word

$$\Delta\phi_w(n) = \frac{f \cdot 2^N}{f_{clk}} \tag{11}$$

Where, f is Carrier DCO frequency that contained Doppler shift $f = L_1 + f_{doppler,i,j}$.

E. Deal with Difference Data[5]

Based on the configuration of the base stations simulator directly calculates the effects of satellite ephemeris error and electric wave refraction error on difference receiver, and gets x, y, z difference data, then send them to moving CAPS receiver in standard difference data format.

IV. EXPERIMENTAL RESULTS

The results from experiment show that bias of mean of longitude, latitude and altitude are 0.2632m, 0.6080m and 0.2318m respectively; bias of mean of speed is 0.0764m/s. Variance is 0.2195 when the space vehicle is moving in 300m/s, but they are 0.2004m/s and 0.15094 respectively when in 500m/s.

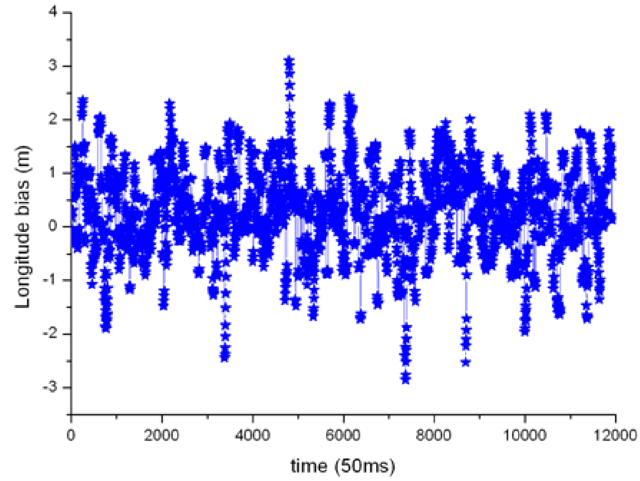

Figure 4. Longitude direction

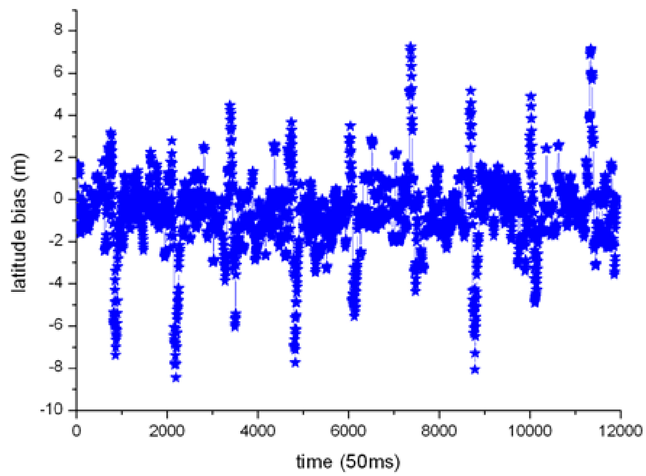

Figure 5. Latitude direction

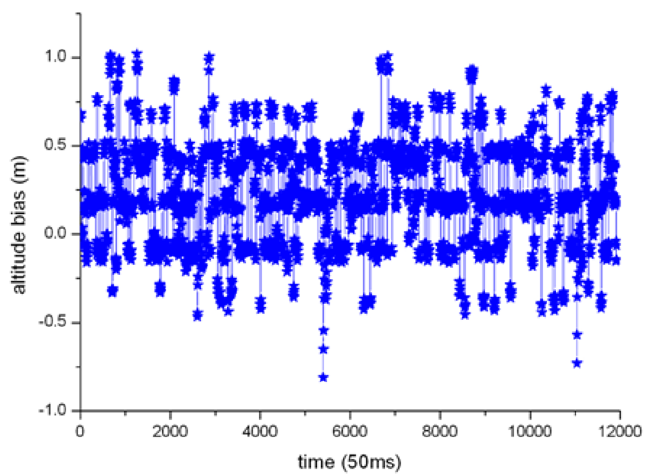

Figure 6. Altitude direction

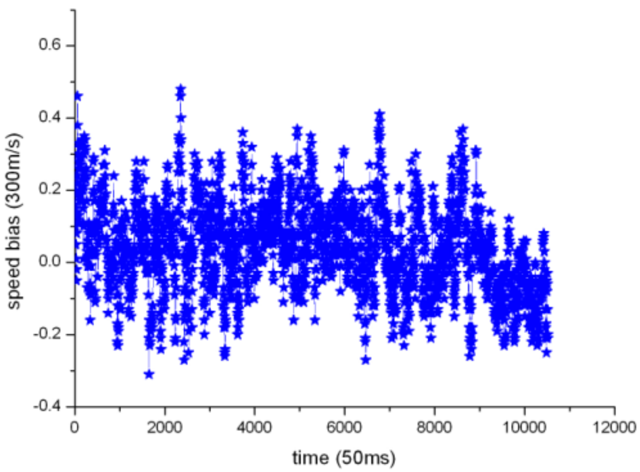

Figure 7. Speed bias (300m/s)

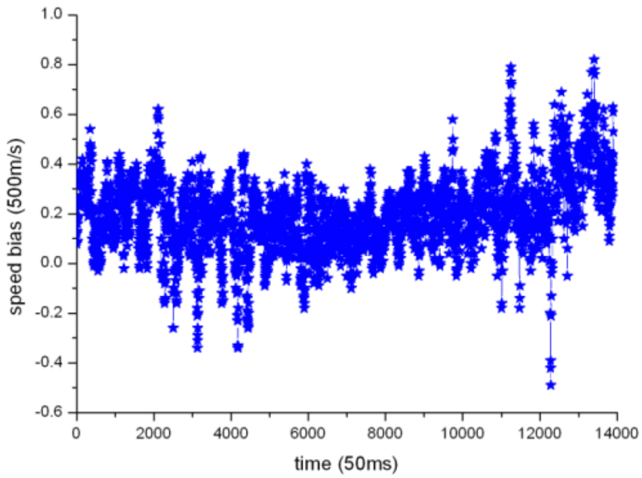

Figure 8. Speed bias (500m/s)

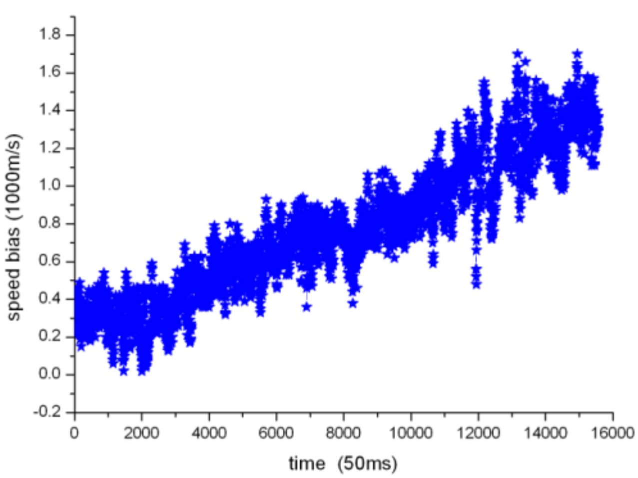

Figure 9. Speed bias (1000m/s)

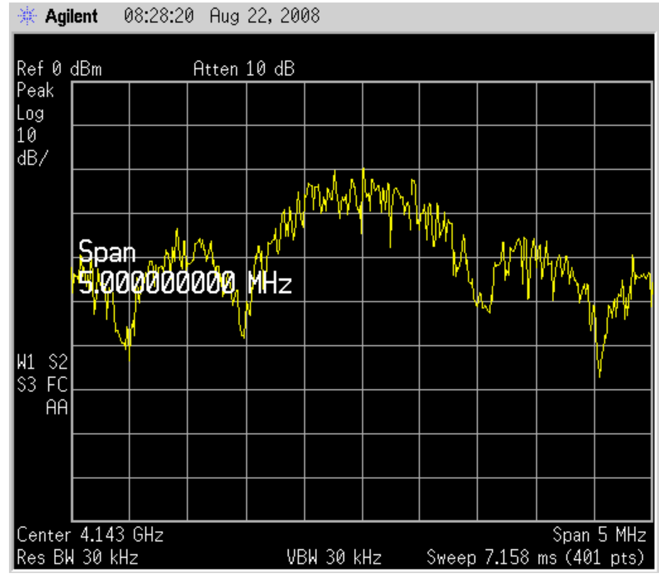

Figure 10. Radio frequency CAPS signal

V. CONCLUSION

This paper gives the structure and key technologies of CAPS simulation testing system, and gives experimental results. CAPS stimulator test system has the characteristics of low-dynamic, middle-dynamic, high-dynamic co-existing testing features; the power of output signal can be adjustable: 0dBm～-130dBm, can be adjusted step 1dB; ranging codes precision can reach ±0.001meters (RMS); measurable speed range ± 2000m/s; measurable acceleration ± 200m/s^2; Jerk(the time rate of change of acceleration) ± 20m/s^3; it can be on-the-spot debugging and its software can be upgraded.

ACKNOWLEDGMENT

The authors would like to thank Professor Shen Kai-Xian for his checking on the English manuscript of this paper. We also thank Dr. Wu JianFeng, Dr. Hou Lei and Dr. Wei JingFa for helpful discussion in this work.

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