A New Direct Radio Frequency Generation Technology for Downlink Navigation Signals

Zhimei Yang(✉), Lingling Chen, Hao Tang, and Lixin Zhang

Xi'an Institute of Space Radio Technology, Xi'an 710100, China

Abstract. In order to effectively solve the influence of satellite navigation signal generation equipment on the fixed ambiguity, the Beidou high-precision signal radio frequency direct generation technology is studied, which can effectively separate the initial phase of the carrier phase and the hardware delay in the channel, and reduce the carrier phase fractional deviation caused by the spaceborne device to reduce the ambiguity. The influence of the fixed degree can effectively solve the consistency of the pseudo code and the carrier, so that the phase of the carrier and the pseudo code is fixed, and the phase relationship will not change with the passage of time, so as to realize the consistency of the navigation signal and ensure the generation of the signal carrier. The stability of the initial phase of the phase reduces the influence on the estimation of the fractional fluctuation of the carrier phase, thereby improving positioning accuracy.

Keywords: Direct radio frequency generation · Carrier phase · Carrier pseudo code consistency

1 Introduction

At present, Beidou-3, GPS III, and Galileo satellites all adopt the intermediate frequency navigation signal generation scheme [1], that is, the baseband signal is directly modulated with the intermediate frequency carrier in the digital domain after being generated, and then sent to the DAC, and then modulated on the carrier to generate the radio frequency signal. However, because the generation path of the carrier and the baseband signal is not completely consistent, due to temperature changes or device aging, the phase of the carrier and the pseudo code cannot be guaranteed to be consistent, resulting in a decimal deviation of the carrier phase at the satellite, and fluctuations with temperature and aging. In order to effectively solve the influence of satellite navigation signal generating equipment on the fixed ambiguity, the primary principle of satellite navigation signal generation is that the phases of the three elements of the carrier, ranging code, and telegram in the navigation signal are strictly consistent, and do not change over time, at least to ensure that it is stable, Predictable.

To this end, this paper proposes a new radio frequency signal direct generation technology, which uses the digital domain to directly generate radio frequency navigation signals, effectively separating the initial phase of the carrier phase and the hardware

X. Wang et al. (Eds.): AICON 2021, LNICST 396, pp. 362–371, 2021.
https://doi.org/10.1007/978-3-030-90196-7_30

delay in the channel, and reducing the carrier phase fractional deviation caused by the spaceborne device to fix the ambiguity. The influence of, can effectively solve the consistency of pseudo code and carrier.

2 Signal Generation Design

Different from the previous intermediate frequency signal generation technology, the digital radio frequency signal generation is to generate the baseband signal and the carrier signal separately and then perform quadrature modulation in the digital domain, and then generate the radio frequency navigation signal through digital-to-analog conversion. The principle block diagram is shown as in Fig. 1.

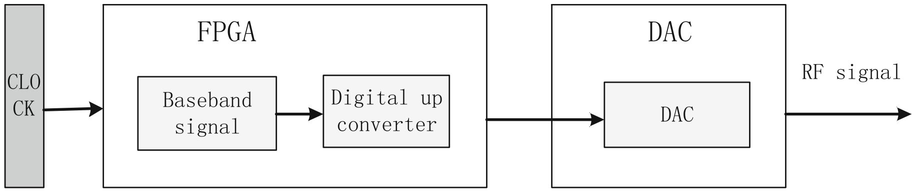


Fig. 1. Direct digital radio frequency modulation.

The direct generation of radio frequency signals is based on the principle of high Nyquist zone signal generation [2]. The principle of high Nyquist zone signal generation is that the sample-and-hold circuit converts the digital signal into a continuous analog signal when the signal is converted by the DAC. The sampling frequency fs is attenuation of the Sinc function at the zero point. As a result, multiple Nyquist zones are formed. These Nyquist zones are divided by fs/2 and have a mirror image relationship with respect to fs/2. Using the image signal in the high Nyquist region as an effective signal for work can make the sampling rate lower, and perform digital processing in the digital domain with a lower clock frequency.

The radio frequency navigation signal needs to generate baseband elements and carrier elements at the same time. The two main principles of the direct radio frequency signal generation scheme are: firstly, ensure the integer characteristics of the generated elements, that is, the clock of the generated elements is an integer or fractional relationship; secondly, the elements are deterministic Relationship. Analyzing each frequency signal, the minimum constant envelope baseband signal generation frequency is shown in Table 1, and its least common multiple is 859.32 MHz, that is, all baseband information can be accurately generated under 859.32 MHz. Considering the baseband signal, the sampling frequency should be able to ensure the accurate generation of messages, sub-codes, codes, and sub-carriers.

It can be seen from the above analysis that using the same clock, it is impossible to generate the elements of the three frequency points in integers. Therefore, consider using clock generation for each of the three frequency points, and then use a synchronization design to ensure synchronization. The signal center frequency and bandwidth have been fixed. The Mix mode of the radio frequency DAC device is used to ensure

Table 1. Carrier frequency factor.

Signal	Center frequency/MHz	Factor
B1	1575.42	$154 \times 10.23 = 2 \times 7 \times 11 \times 10.23$
B2	1191.795	$233 \times 5 \times 1.023$
B3	1268.52	$124 \times 10.23 = 4 \times 31 \times 10.23$

the maximum output power [3, 4] (DAC Mix mode). At this time, the signal generation clock (sampling frequency) needs to be equivalent to the signal center frequency, and the sampling frequency is about 900 ~ Between 1800 MHz.

The baseband signal and the radio frequency carrier signal need to be accurately generated at the same time under the sampling clock, which requires:

$$\begin{cases} N(f_S - f_{RF}) = f_S \\ Mf_{BS} = f_S \end{cases} \tag{1}$$

where f_S is the sampling frequency, f_{RF} is the center frequency of the radio frequency carrier, f_{BS} is the baseband signal frequency, N and M is an integer. Take B2 as an example:

B2 IF frequency $f_{BS} = 86.955$ MHz, RF frequency $f_{RF} = 1191.795$ MHz, sampling frequency $f_S = 1104.84$ MHz, because 1104.84/86.955 = 12.7, the IF carrier generated by the signal cannot be divided evenly. Therefore, the design plan will adopt a double conversion design:

$$\begin{cases} N(f_S - f_{RF}) = f_S \\ Mf_{BS} = f_S \end{cases} \text{Becomes} \begin{cases} f_1 + f_2 = f_S - f_{RF} \\ Pf_1 = f_S \\ Qf_2 = f_S \\ Mf_{BS} = f_S \end{cases} \tag{2}$$

where P and Q can be exchanged. Therefore, the sampling rate that can be selected is shown in Table 2:

Table 2. B2 signal sampling rate analysis.

M	*P*	*Q*	Remarks
9	12	216	92.07–5.115 = 86.955
9	24	27	46.035 + 40.92 = 86.955

Here are two options (the two options have the same hardware, only the design parameters are changed):

(1) Configuration scheme one.
86.955 = 46.035 + 40.92 MHz, for 46.035 MHz, 24 points per cycle; for 40.92 MHz, 27 points per cycle.
(2) Configuration scheme two.
86.955 = 92.07–5.115 MHz, for 92.07 MHz, 12 points per cycle; for 5.115 MHz, 216 points per cycle.

The performance of the two designs is similar. Because 92.07 MHz is a multiple of 5.115 MHz in the second configuration, all elements of the carrier can be generated at the 1104.84 MHz sampling frequency, so the design is simpler, so when $M = 9$, $P = 12$, $Q = 216$ When, it is the preferred solution.

3 Test Verification

A test platform was set up as shown in Fig. 2. The digital radio frequency signal generation unit sends out three radio frequency signals. In order to prevent spectrum aliasing, it needs to pass through the filter before entering the signal acquisition equipment; to ensure the sampling accuracy, the signal acquisition equipment and the signal generation unit are of the same source.

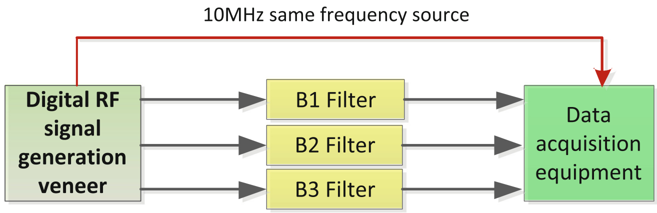


Fig. 2. Block diagram of test equipment connection.

This section takes the B2a signal as an example for simulation verification. The B2a signal [5] is QPSK modulation, the code rate is 10.23 Mbps, and the carrier frequency is 1176.45 MHz. In order to measure the main performance indicators of the direct radio frequency signal, the signal quality is examined from the three aspects of frequency domain, correlation domain and time domain. The specific index requirements [6] and simulation results are shown in Table 3, and the simulation diagrams are shown in Fig. 3 and Fig. 4.

Through simulation verification, it can be seen that the direct radio frequency signal is evaluated in the frequency domain, correlation domain, and time domain, and the results all meet the indicators, and the signal quality is very good.

Table 3. Signal quality index requirements and simulation results.

Category	Name	Index requirements	Results
Frequency domain characteristics	Synthetic power spectrum deviation	≤0.5 dB	0.153
Related domain characteristics	Related losses	≤0.5 dB	0.03
	S-curve zero crossing deviation	≤0.5 ns	0.0336
Time domain waveform	Baseband signal waveform distortion	≤5 ns	0.031

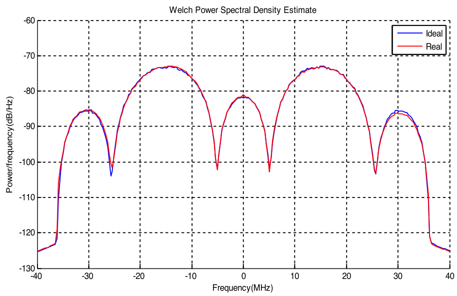


Fig. 3. Power spectrum

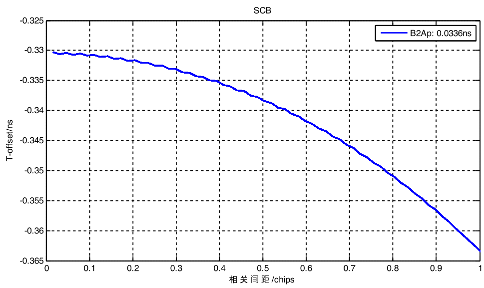


Fig. 4. S Curve zero crossing deviation.

In order to verify the superiority of the signal directly generated by the radio frequency in the phase relationship of the carrier pseudo-code, the two methods of long-term evaluation after a single power-on and multiple power-on and power-off methods were used to test and verify. Data collection is divided into the following two situations: (1) Long-term power-on operation of the navigation signal generation unit, data collection every other day, each collection is 3 s, a total of 6 sets of data are collected to verify the carrier pseudocode phase relationship Stability and predictability; (2) The navigation signal generating unit is powered on and off for 6 times, and each time is collected for 3 s, a total of 6 sets of data are collected to verify the carrier pseudocode phase relationship under different power on and off conditions Consistency.

The software receiver is used to separately capture and track each signal of the collected data [7], and obtain the pseudorange measurement value and carrier phase measurement value of each signal component. Assuming that within the 1 ms time period, the receiver has been locked to the carrier without loss of lock and cycle of the carrier. Therefore, the value of the round ambiguity N in the measured value of the carrier phase remains unchanged at each time. The pseudorange and carrier phase of two adjacent epochs are subtracted separately, then the pseudorange change $\Delta\rho_k$ and the carrier change $\lambda \cdot \Delta\phi_k$ in units of distance should theoretically be equal. Ideally, the difference between the pseudorange change $\Delta\rho_k$ and the integrated distance $\lambda \cdot \Delta\phi_k$ indirectly reflects the phase difference between the code phase and the carrier phase when the transmitted signal is generated.

According to the above software receiver method for analysis, Fig. 5 shows the software receiver acquisition and tracking process:

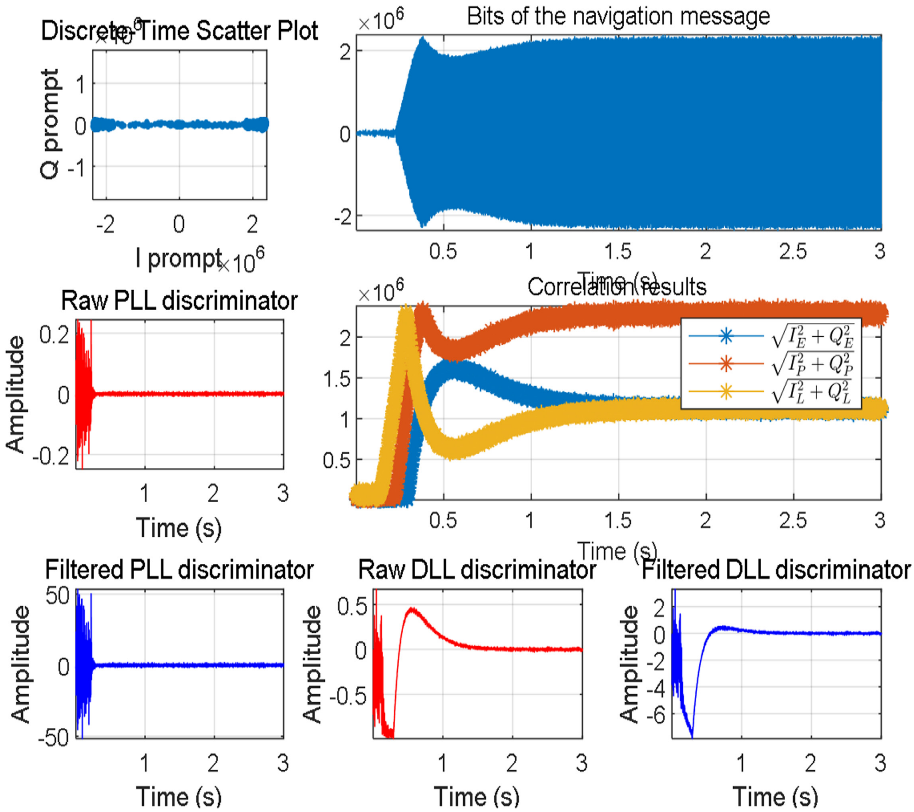


Fig. 5. Software receiver to capture tracking results.

It can be seen from Fig. 5 that the software receiver has entered stable tracking after 1 s, so the last second of stable data in the 3 s data is analyzed according to the above method. The simulation result of the carrier pseudo-code coherence is shown in Fig. 6.

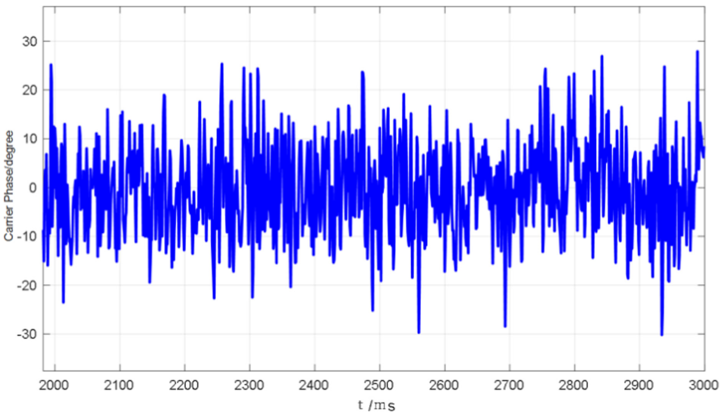


Fig. 6. Direct RF signal carrier pseudo-code coherence (the last second of the 3-s data).

(1) Stability analysis of the phase relationship of the pseudo-code download wave during long-term power-on and stable state.
The 6 groups of data collected in the first case were captured and tracked with the software receiver, and the last second data after the tracking was stabilized was analyzed according to the above method, and averaged every 100 ms. For intuitive reflection, the 6 groups were simulated The result combination is displayed on a simulation graph, and the carrier pseudo-code coherence result is shown in Fig. 7.

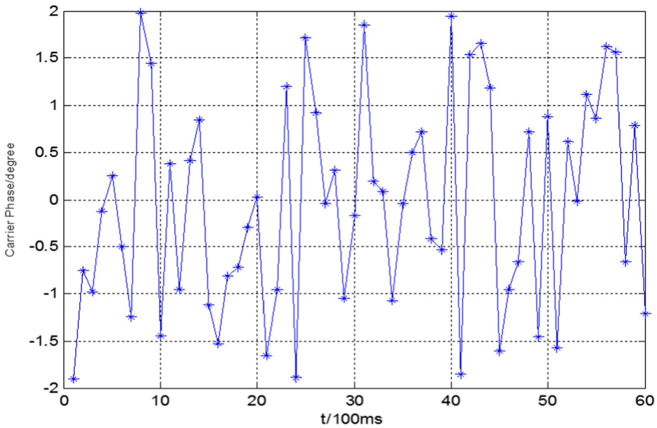


Fig. 7. Carrier pseudo-code coherence of 6 groups of 3S data of direct radio frequency signal.

From the analysis of Fig. 7, it can be seen that the long-term (6 days) carrier pseudo-code phase difference of the direct radio frequency signal after a single power-on is very stable, stable around 0°, and the fluctuation does not exceed 2°. The carrier pseudo-code phase relationship has good long-term stability.

(2) Analysis of the consistency of the phase relationship of the pseudo-codes in the state download waves of multiple power on and off.

In order to compare with the direct RF signal in the second case, the IF upconversion data of the traditional scheme was collected at the same time, as shown in Fig. 8, the data was collected from the triplexer outlet, and the IF signal generation unit was powered off respectively. A total of 6 sets of data are collected for 3 s each time.

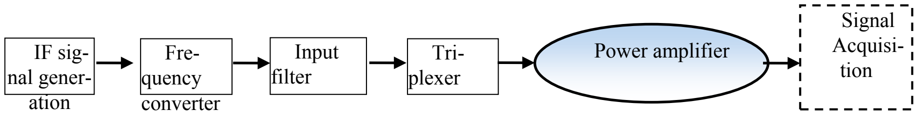
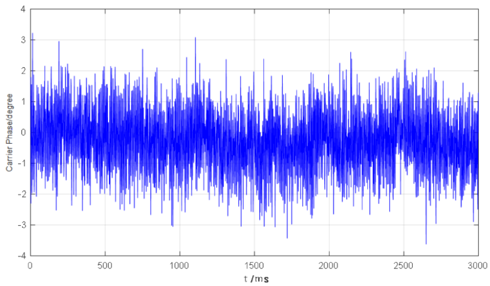
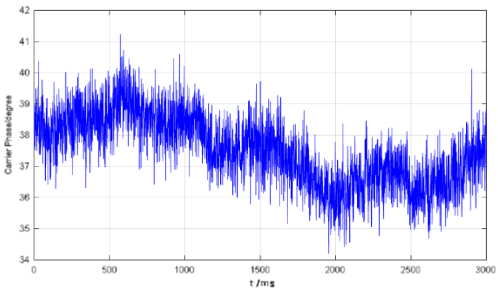


Fig. 8. Block diagram of IF up-conversion data acquisition.

The first group of 3 s signals in the collected direct RF signal and IF up-conversion signal are analyzed according to the above method respectively, and the simulation results of the carrier pseudo-code coherence are obtained as shown in Fig. 9.



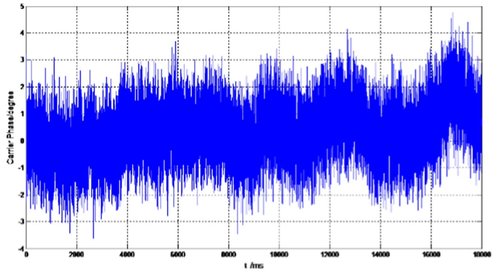
(a) Direct RF signal



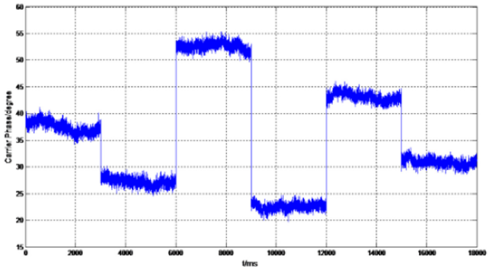
(b) IF upconverted signal

Fig. 9. Comparison of the coherence between radio frequency generation and intermediate frequency up-conversion carrier pseudo-code.

Each time the machine is turned on and off, a set of 3 s data is collected and analyzed according to the above method. 6 sets of direct radio frequency data analysis results and 6 sets of intermediate frequency up-conversion data analysis results can be obtained. In order to directly reflect the difference from the figure, 6 sets of the analysis result combination is displayed on a graph, as shown in Fig. 10.



(a) Direct RF signal



(b) IF upconverted signal

Fig. 10. Carrier pseudo-code coherence between RF generation and IF up-conversion 6 groups of 3 s data.

By analyzing the results in Fig. 10(a), it can be seen that the phase difference between the pseudo code and the carrier is very stable every time the direct radio frequency signal is turned on and off, and it is stable at about 0.4°, and the fluctuation does not exceed 2°. However, it is easy to see from Fig. 10(b) that the phase difference between the pseudo code and the carrier wave of the intermediate frequency up-conversion signal is not a stable value every time it is switched on and off, and fluctuates greatly, with the fluctuation range reaching tens of degrees, while the direct radio frequency signal is switched on and off many times. The consistency of the phase relationship of the pseudo-code of the machine state download wave is good. The semi-physical simulation results are in good agreement with the previous conclusions when discussing the advantages of direct RF signals over IF upconverted signals.

4 Conclusions

In order to solve the influence of the satellite navigation signal generation equipment on the ambiguity fixation in the fixed ambiguity factor, this paper proposes a new radio frequency direct generation technology, and takes B2 as an example to verify it through experiments. The direct radio frequency signal is from the frequency domain and the correlation domain. It is evaluated in terms of time domain and other aspects, and the results all meet the indicators, and the signal quality is very good; the direct RF signal has passed the long-term copy machine assessment, and the carrier pseudo-code phase relationship has good long-term stability; the direct RF signal has a pseudo-code when the machine is switched on and off many times. The phase difference with the carrier is very stable, and the phase relationship of the carrier pseudo code has good consistency. The new radio frequency generation method can make the phase of the carrier and the pseudo code fixed, and the phase relationship will not change with the passage of time, ensuring the stability of the initial phase of the generated signal carrier, reducing the influence on the estimation of the carrier phase decimal fluctuation, thereby improving positioning accuracy.

References

1. Xie, J.: Satellite Navigation System and Technology. Beijing Institute of Technology Press, Beijing (2018)
2. Pany, T., Eissfeller, B.: Code and phase tracking of generic PRN signals with sub-Nyquist sample rates. Navig. Wiley Online Libr. **51**(2), 143–159 (2004)
3. Gutierrez-Aitken, A., Matsui, J., Kaneshiro, E.N., et al.: Ultrahigh-speed direct digital synthesizer using InP DHBT technology. IEEE J. Solid-State Circ. IEEE **37**(9), 1115–1119 (2002)
4. Li, X.P., Wang Z.G., Zhang, Y., et al.: 12-bit 2.6 GS/s RF DAC based on return-to-zero technology. J. China Univ. Posts Telecommun. **26**(4), 36–42 (2019)
5. Yuan, L.F., Guo, C.J., Zhan, H.Y.: A new signal modulation for compass B2 band. Sci. Technol. Eng. **14**(19), 243–247 (2013)
6. Ouyang, X.F.: Evaluation Technology and Analysis of BDS Signal Quality. National University of Defense Technology, Changsha (2013)
7. Xie, G.: Principles of GPS and Receiver Design [M]. Publishing House of Electronics Industry, Beijing (2009)