

## Research Article

# Experimental Research on Narrowband Interference Suppression of GNSS Signals

Bin Wang,<sup>1</sup> Yanjing Sun ,<sup>1,2</sup> Yang Liu,<sup>1</sup> Yuzhi Zhang,<sup>1</sup> and Song Li<sup>2</sup>

<sup>1</sup>School of Communication Engineering, Xi'an University of Science and Technology, Xi'an 710054, China

<sup>2</sup>School of Information and Control Engineering, China University of Mining and Technology, Xuzhou 221116, China

Correspondence should be addressed to Yanjing Sun; [yjsun@cumt.edu.cn](mailto:yjsun@cumt.edu.cn)

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The navigation satellites are running at a high altitude of 20000 km from the ground, and the satellite signals arriving at the ground are very weak, such as the C/A code on the L1 band, which is only -160 dBW. In complex urban environments, especially when there is an occlusion, the signal power will be even lower. Low power causes the signal to be easily disturbed, where suppressed interference is the most common method of interference. The purpose of this paper is to experiment with the BPSK and BOC signal system to do the narrowband suppression of interference analysis and set up the actual test environment, based on the commonly used LMS algorithm for the two systems of narrowband interference performance contrast analysis, and throughout the simulation, it can be seen that the two improved algorithms can effectively suppress narrowband interference, thus improving the anti-interference performance of satellite navigation receiver.

## 1. Introduction

The GPS signal power reaching the surface of the earth is weak due to the distance between the satellite and the earth. Usually, the average power of GPS signals on the earth surface is only -133 dBm which makes the GPS receiver susceptible to interference when receiving signals [1–5]. Experiments show that the jammer can interfere with the normal operation of the GPS receiver within 25 km, only when the effective radiation power (ERP) of the jammer reaches 1 W.

The essence of suppressing jamming is to use jammer to transmit interference signal with strong interference energy, which can make the real signal blurred or completely submerged, to cause the user terminal receiver cannot receive useful signals [6, 7]. The suppression jamming can be divided into narrowband interference and broadband interference, where narrowband interference is a very high cost performance interference mode for interfering the main lobe of the navigation signal [8, 9]. The interference suppression technology can be divided into time domain suppression technology and frequency domain suppression technology: (1) the time domain

interference suppression technology uses past interference value to estimate current interference value because of the strong correlation between the interference values and uses the estimated value to filter the current signal. (2) Transform domain narrowband interference suppression technology: the first signal transition time domain into frequency domain signal, half by frequency based on adaptive FFT notch filter technology, etc., to suppress the narrow-band interference in [10, 11] signal received at the receiver.

This paper makes the research on the method for narrowband interference suppression and puts forward the corresponding algorithm for narrowband interference suppression methods that are mainly two categories: in the time domain to suppress the interference, most of the research is mainly the adaptive prediction filter, in the transform domain to suppress the interference, mainly in the FFT frequency domain and wavelet transform interference suppression based on the suppression. The purpose of this paper is to analyze the performance of BPSK and BOC signals in narrowband interference detection and adopt the traditional LMS method.

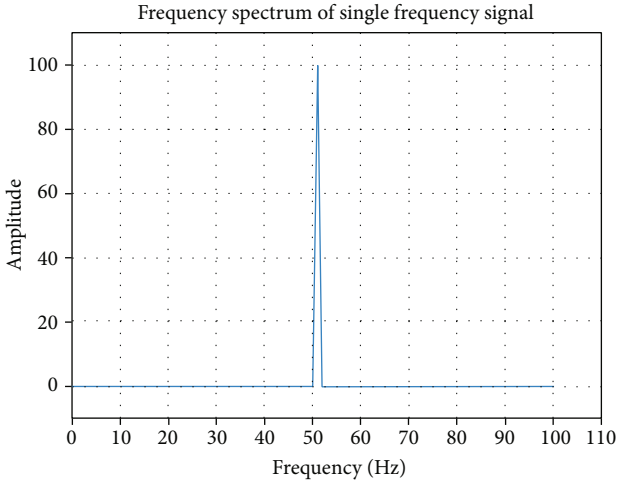


FIGURE 1: Frequency spectrum of single frequency signal.

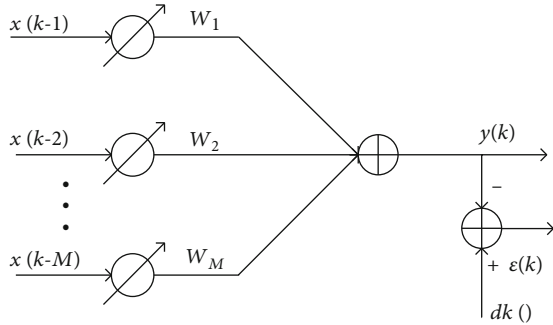


FIGURE 2: Adaptive linear combiner.

This paper analyzes the influence of narrowband interference on BPSK and BOC modulated signals and studies the traditional narrowband interference suppression methods. On this basis, we propose an improved time-domain adaptive algorithm and a frequency block variable step size algorithm based on the traditional LMS algorithm. Experimental results show that the proposed algorithm improves the performance of satellite navigation receiver against narrowband interference.

## 2. Narrowband Interference

In the satellite navigation system, narrowband interference is a very common form of interference. Narrowband interference generation methods are also different, can use autoregressive narrowband interference, and can also be equivalent to multiple single-frequency interference signal superposition; also, the interference signal is regarded as a signal modulated by a narrowband filter. Single frequency interference is a special narrowband signal, which is essentially a single-frequency continuous wave, This interference signal can interfere with one or more frequency points in the satellite navigation system [12–14]. The expression is

$$j(t) = \sqrt{2p_j} \cos(\omega_j t + \phi_j), \quad (1)$$

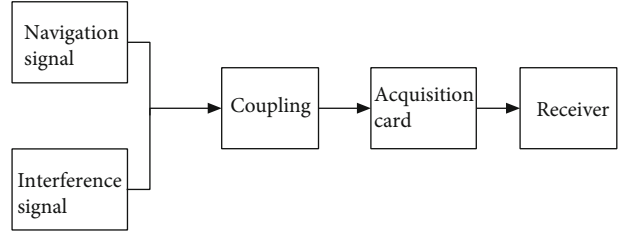


FIGURE 3: Schematic diagram of the experimental platform.

where  $\omega_j$  is the angular frequency of a single tone signal in type (2-1),  $p_j$  is the power, and  $\phi_j$  is the random phase distributed over  $[0, 2\pi]$ . The frequency spectrum of the single frequency signal is shown in Figure 1.

Single frequency interference without obtaining the satellite navigation system pseudocode sequence and pseudocode type, nor need to know the communication pseudocode rate and other technical parameters, only needs to detect the real signal when the signal center frequency. Therefore, as long as there is a high-power single-frequency interference signal and its target signal carrier center frequency transmission, the system cannot work properly, and it is necessary to the system there is a narrow band interference suppression.

## 3. The Basic Principle and Algorithm of Adaptive Filter

**3.1. Principle of the Conventional Time Domain LMS Algorithm.** The core of the adaptive filter is the adaptive linear combiner, and the principle block diagram is shown in Figure 2 and sets the  $M$  inputs of the linear combiner, respectively  $x(k-1), x(k-2) \dots, x(k-M)$ . After the input weight is linear, the  $Y(k)$  is obtained:

$$y(k) = \sum_{i=1}^M W_i x(k-i). \quad (2)$$

Define the weight vector as

$$W = [W_1, W_2, W_3, \dots, W_m]^T. \quad (3)$$

In Figure 2,  $d(k)$  represents the expected response and defines its error signal as

$$e(k) = d(k) - y(k) = d(k) - \sum_{i=1}^M W_i X(k-i). \quad (4)$$

The formulas can be written in vector form:

$$e(k) = d(k) - W^T X(k) = d(k) - X^T(k) W. \quad (5)$$

The purpose of the LMS algorithm is to obtain the weight coefficient which makes the value of  $E\{e(k)^2\}$  minimum.

TABLE 1: Antijamming and antideception test signal system.

Frequency	Center frequency	Branch signal	Modulation	Ranging code Cycle	Code Rate	Message rate	Phase relation
B1	1575.42 MHz	Pilot	BPSK(10)	1 ms	10.23 MHz	50 bps/100 bps	Orthogonal 90 degrees
		Data	BPSK(10)	1 ms	10.23 MHz		
B1	1575.42 MHz	Pilot	TDDM+BOC (14, 2)	10s	1.023 MHz	100 bps	
		Data		10s	1.023 MHz		

Note: messages are not encoded, using the 50 bps message rate. The message is encoded in LDPC, using the 100 sps symbol rate.

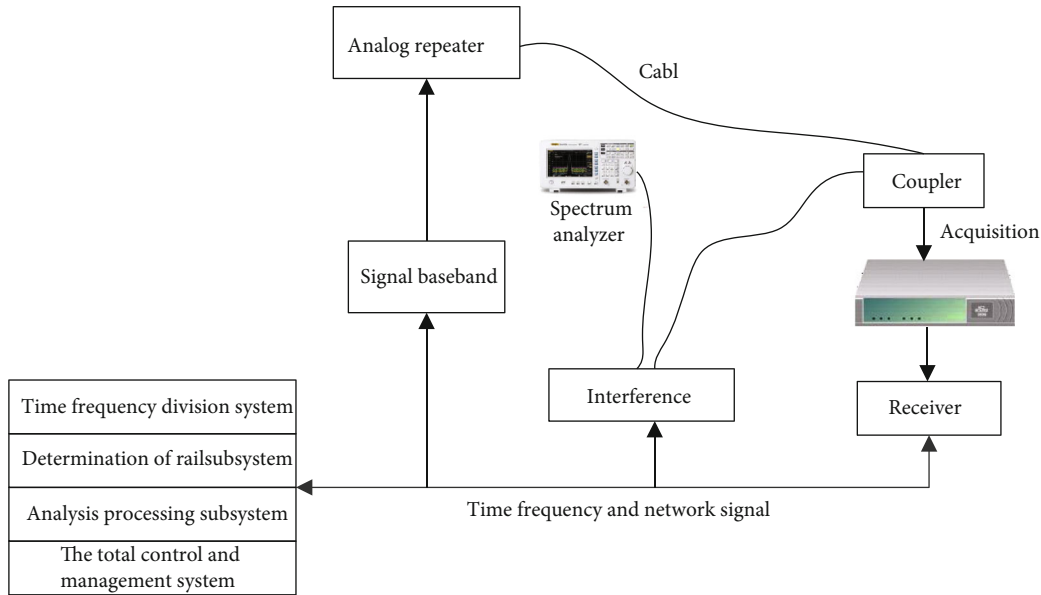


FIGURE 4: Structure of signal acquisition section.

**3.2. Frequency Domain LMS Algorithm Design.** According to the theory of digital signal processing, linear correlation and linear convolution can be realized by means of FFT (fast Fourier transform). Therefore, the frequency domain block adaptive filtering algorithm is implemented by iteratively updating the weight vector of the filter in the frequency domain by FFT. The frequency domain block adaptive filtering algorithm implemented in this method is called frequency domain block LMS adaptive filtering algorithm, which was first proposed by Clark.

In the algorithm design, frequency LMS adaptive filtering is adopted, and the improved principle of time domain LMS algorithm is utilized. When the desired signal is not easily obtained, the narrowband interference can be estimated in the frequency domain because the magnitude of the narrowband interference in the spectrogram is far greater than the amplitude of the normal signal. The estimated signal is used as the intermediate signal of the algorithm, the original narrowband interference signal is regarded as a useful signal, and the navigation signal is taken as an interference signal. Then, the adaptive filtering algorithm of frequency domain block LMS is used to filter.

## 4. Setting Up Experimental Environment

**4.1. Experiment Platform Principle.** The experiment revolves around the satellite forwarding platform and uplink station, respectively, to produce BPSK (10) and BOC (14,2) modulation signal, amplified by the power emitted by the antenna to the satellite uplink signals, and satellite transmission platform receives the uplink signal, the uplink signal forwarding, and downlink transmission signal to the ground. The receiving terminal is placed near the interference source and interference source signal generator to produce various types of interfering signals and can realize the power and frequency adjustable. The satellite signal and direct access to the narrowband interference signal applied to the receiving terminal are coupled by a cable connected, no signal interference of the external environment, and then by the data collection card to collect, then collected the data into the acquisition and tracking, demodulation by computer software receiver, and analysis of the test results. The schematic diagram is shown in Figure 3:

Among them, the signal system of navigation signals used in the experiment is shown in Table 1, the signal acquisition



FIGURE 5: Signal generator and spectrum analyzer.

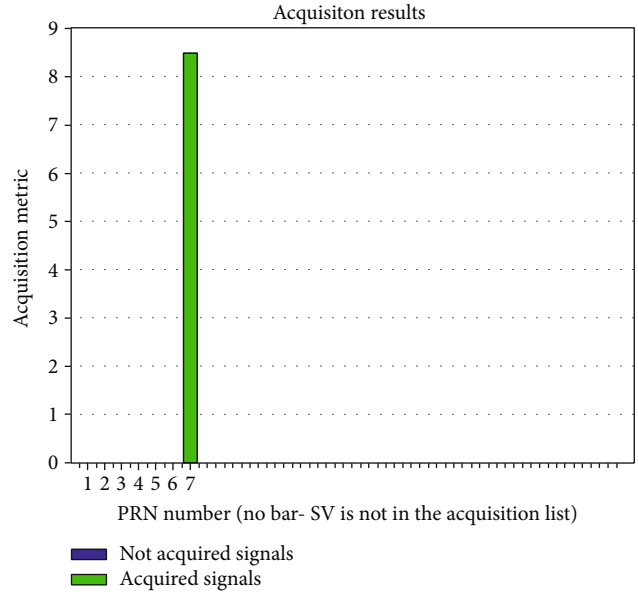


FIGURE 7: Capture of the original signal.

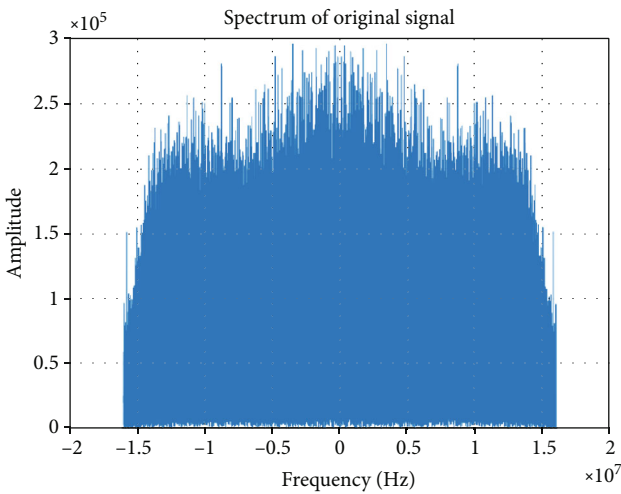


FIGURE 6: Spectrum of original signal.

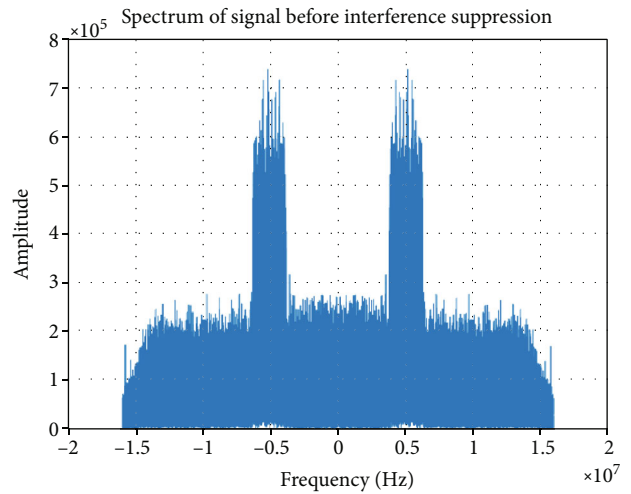


FIGURE 8: Spectrum of signal before interference suppression.

part is obtained through the acquisition card, the interference signal is produced by Agilent N5172B, and the signal generator can produce a variety of common signal and the signal generated power and adjustable bandwidth.

4.2. *Hardware Composition in the Experiment.* The hardware structure of the experiment is shown in Figure 4,

Some of the other hardware devices in the experimental design are shown below:

The signal generator is shown in Figure 5:

In the anti-jamming experiment of navigation signal, the C band navigation signal produced by ground station base-band is changed into L band by the analog repeater of ground station and transmitted to coupler through cable. The interference signal produced by the signal generator is connected to the receiving end by the cable and the spectrum analyzer.

The coupler navigation signal and interference signal coupling are coupled by the signal acquisition card for data acquisition, then collected the data into the capture, tracking, and demodulation by computer software receiver. At the same time, the interference signal is analyzed and detected by spectrum analyzer.

When the experimental equipment is in normal operation, the analog transponder output L band frequency point is 1575.42 MHz, and the EIRP value remains constant during the test period. The signals received by omnidirectional antennas are collected in the workstation after the sampling card was set, and each segment of data is transmitted to the workstation and processed by a software receiver for capturing, tracking, and anti-jamming.

4.3. *Experimental Results and Analysis.* The following is a specific experiment to verify the proposed algorithm for

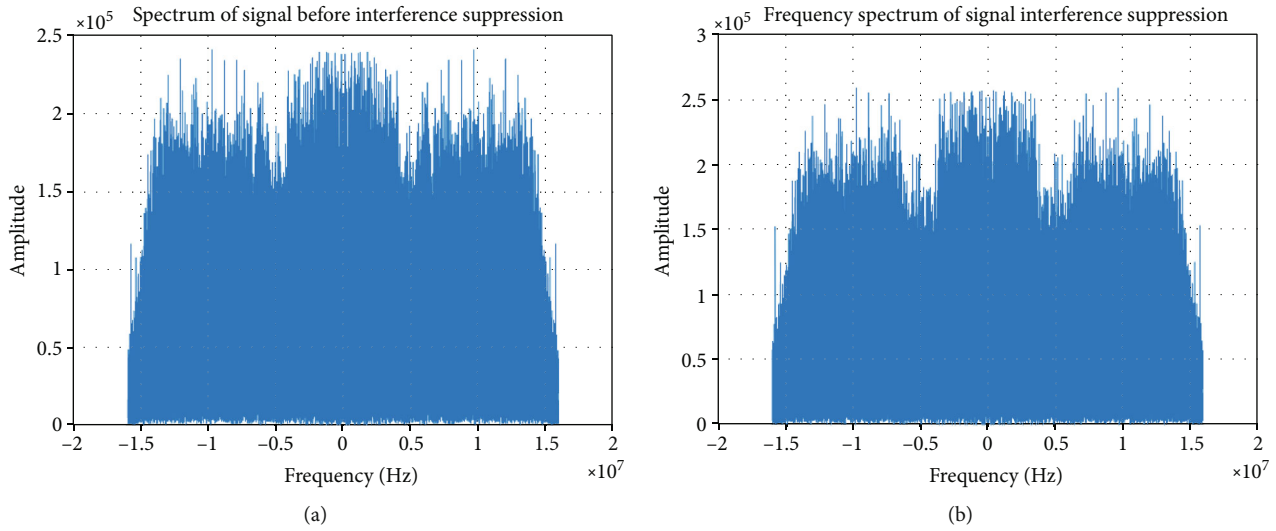


FIGURE 9: Frequency spectrum of signal after interference suppression.

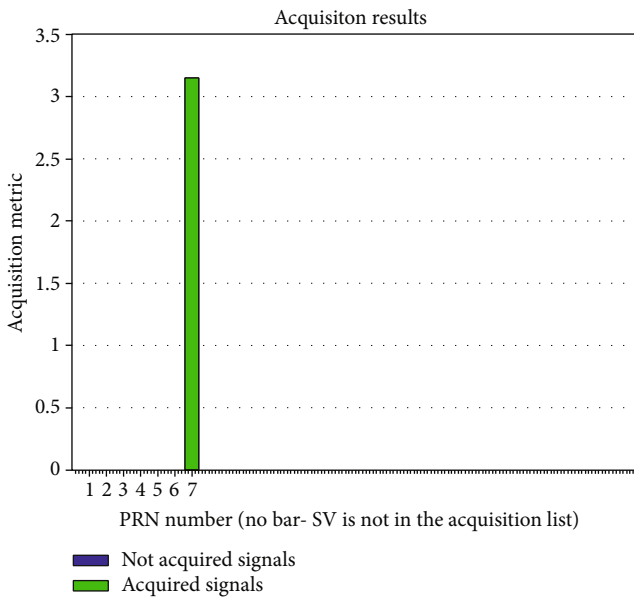


FIGURE 10: Capture plots before interference suppression.

various interference suppressions in navigation signals. The validity and correctness of the method are analyzed. Specific experiments can be divided into two parts according to the different types of interference signals.

#### 4.3.1. Narrowband Interference Suppression Experiment

(1) *Experiment 1: Navigation Signal Calibration Experiment.* A set of B1 signals is obtained by sampling, the central frequency is 1575.42 MHz, the code rate is 10.23 MHz, and the period is 1 ms. In the absence of interference, the satellite signal power is evaluated using a spectrograph. The ground station generates a navigation signal according

to the preset signal system, and the analog transponder transfers the signals through the cable wires. At the receiving end, the signal power spectrum analysis instrument used to collect the data acquisition card, then collected the data into the software receiver workstation. It can be seen from Figures 6 and 7 that the measured signal can be easily captured and tracked within the receiver.

(2) *Experiment 2: Narrowband Interference Suppression Experiments for BPSK (10) Modulated Signals.* In the interference signal frequency interference in the signal center frequency near 1575.42 MHz by signal generator, frequency interference by this experiment was 1580.42 MHz, and the bandwidth was 2 MHz. In a narrowband interference signal with a signal to interference ratio of 25 dB, coupled by a navigation signal coupler with experiment 1, after the acquisition, the storage devices will transfer the signal the data to the workstation software receiver, and using the method proposed in this paper to suppress narrowband interference, interference suppression and navigation signal spectrum, capture diagram, constellation map, and navigation chart is shown as follows.

The spectrum before and after narrowband interference suppression is as follows:

With the SNR for narrowband interference in 25 dB signal, it can be seen from Figure 8, due to the presence of narrowband interference, the original navigation signal spectrum with narrowband interference is very obvious peaks in the band. The signals are analyzed by time-domain filtering and frequency filtering processing, signal spectrum in Figures 9(a) and 9(b) is shown, (a) is the time-domain filtering algorithm to interfere with the suppression spectrum and (b) is the frequency domain filtering algorithm to interfere with the suppression spectrum, and the signal spectrum has been significantly improved from the signal spectrum and narrowband interference peak basically suppressed.

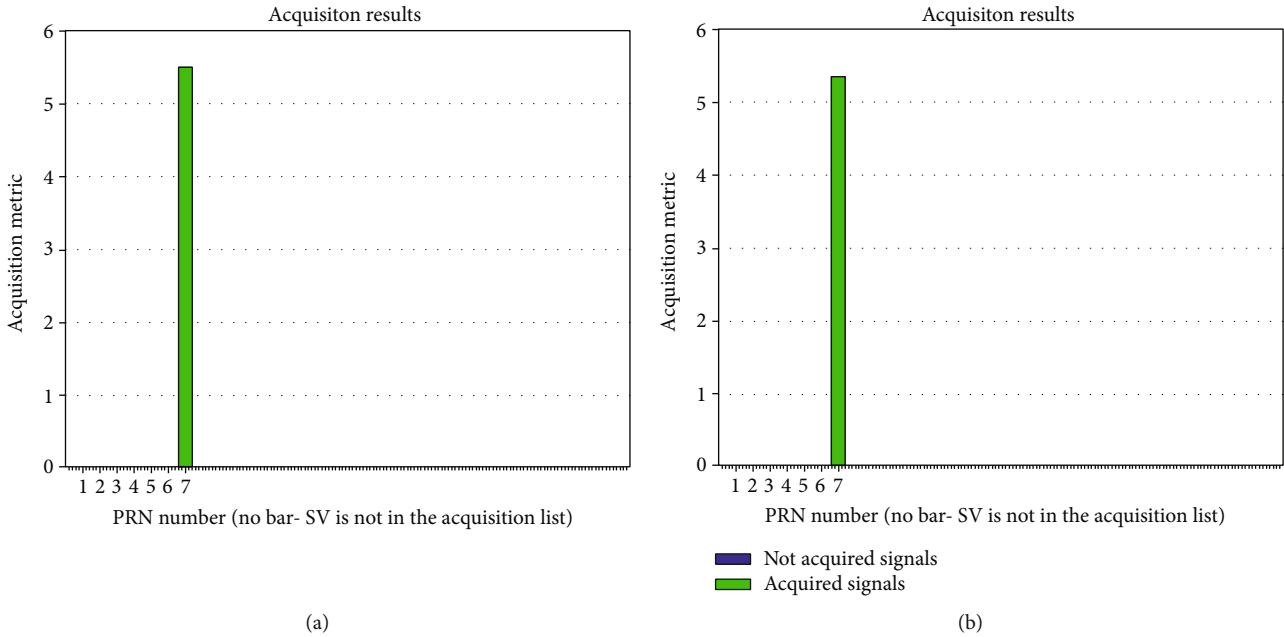


FIGURE 11: Frequency spectrum of signal after interference suppression.

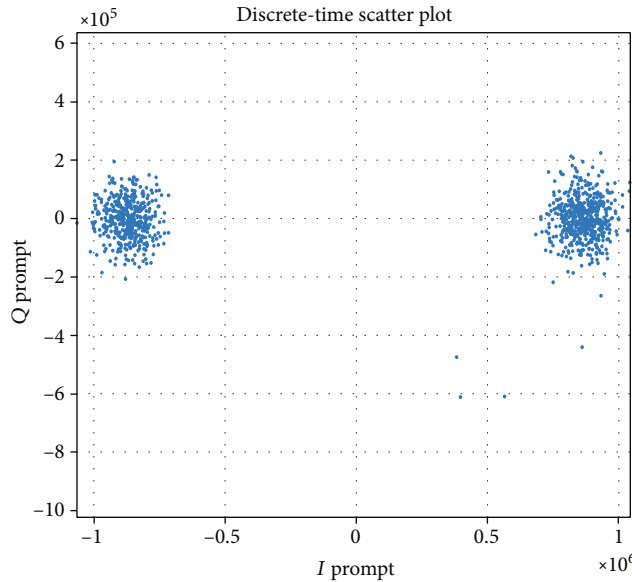


FIGURE 12: Constellation before interference suppression.

Capture plots before and after narrowband interference suppression:

It can be seen from Figure 10 that the signal can be captured after narrowband interference, but its capture performance is obviously weakened, and then compared with the signal acquisition after time domain and frequency domain filtering algorithm. Figure 11 is where Figure 11(a) and 11(b) are captured in time domain and frequency domain, respectively. After the narrowband interference is suppressed, the capture performance of the signal is improved

obviously, which indicates that the interference suppression algorithm proposed in this paper achieves the purpose of suppressing narrowband interference.

The constellation diagram and navigation message diagram before and after narrowband interference suppression are shown below:

It can be seen from Figures 12–16 that the navigation signal quality is improved obviously when the interference suppression algorithm is added, and the tracking performance of the signal is improved. The interference suppression of the



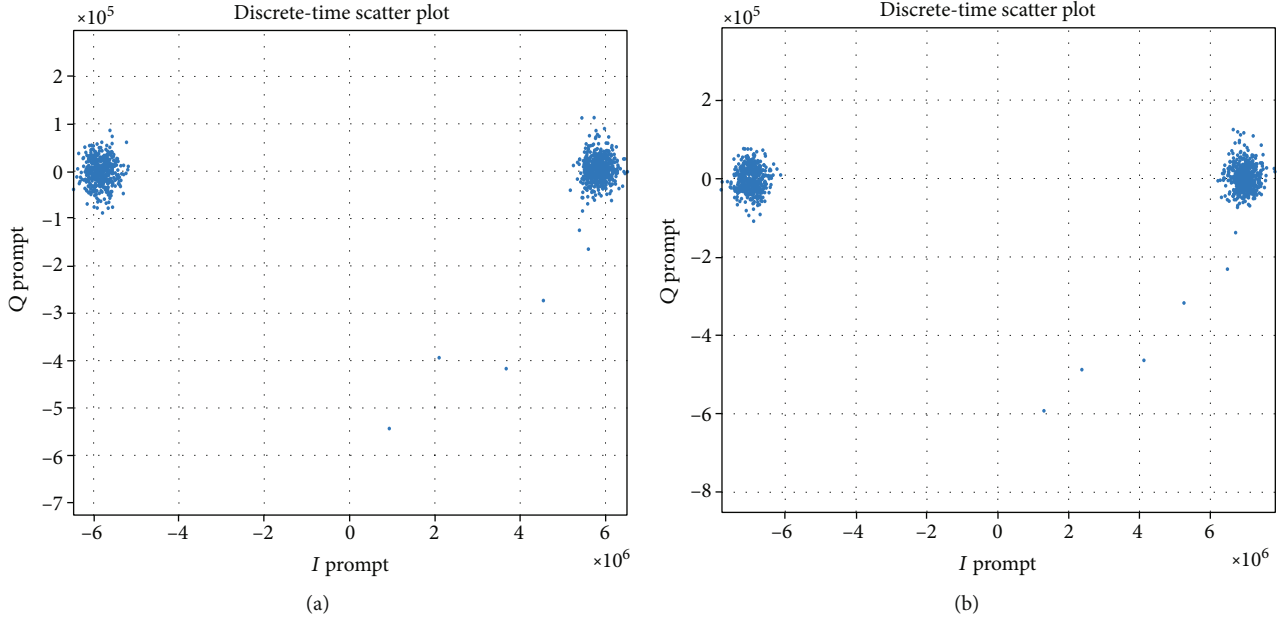


FIGURE 13: Frequency spectrum of signal after interference suppression.

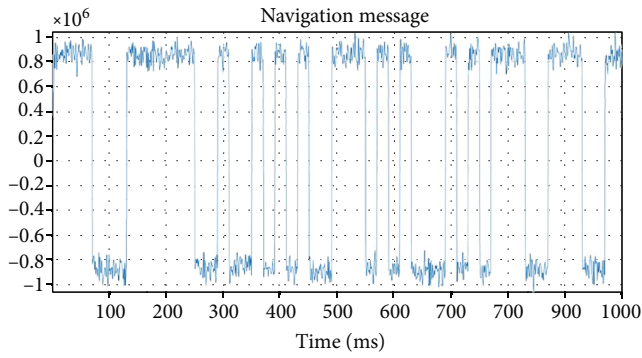


FIGURE 14: Navigation message diagram before interference suppression.

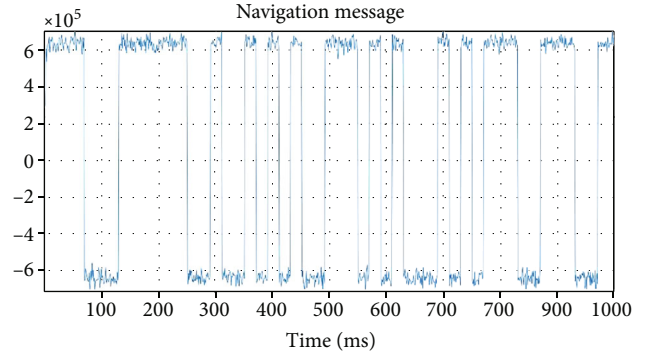


FIGURE 16: Navigation message after filtering in frequency domain.

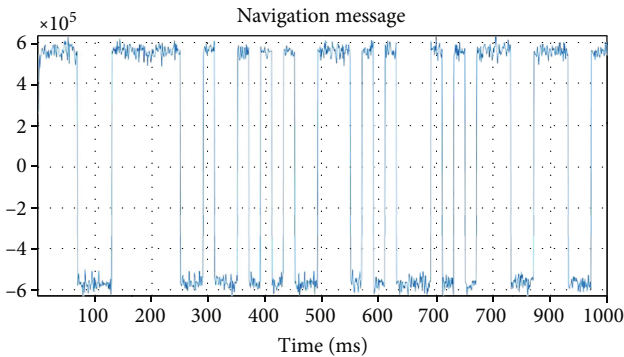


FIGURE 15: Navigation message after filtering in time domain.

frequency domain filtering algorithm can be seen the capability is stronger than the time domain filtering algorithm. The validity of the applied filtering algorithm is proved.

The interference signal with the interference ratio of 25 dB is added to the navigation signal in experiment 1, and the ranging accuracy and the carrier-to-noise ratio before and after the interference suppression are obtained by the two algorithms.

From the above Table 2, it can be seen clearly that the accuracy of the range measurement is obviously improved, and the carrier-to-noise ratio is raised from 51.614190 dB to 55.632159 dB and 56.231299 dB, respectively, after filtering the signals with narrowband interference. The proposed narrowband interference suppression algorithm has a good inhibitory effect on narrowband interference in navigation satellite navigation signals. At the same time, it can be seen that the frequency domain filtering algorithm is better for narrowband interference suppression.

TABLE 2: Records of experimental data.

Algorithm	SIR (dB)	Ranging accuracy	C/N (dB)
Interference free suppression algorithm	25	9.002758	51.614190
LMS filtering algorithm in time domain	25	4.182243	55.632159
Frequency domain block LMS algorithm	25	4.094436	56.231299

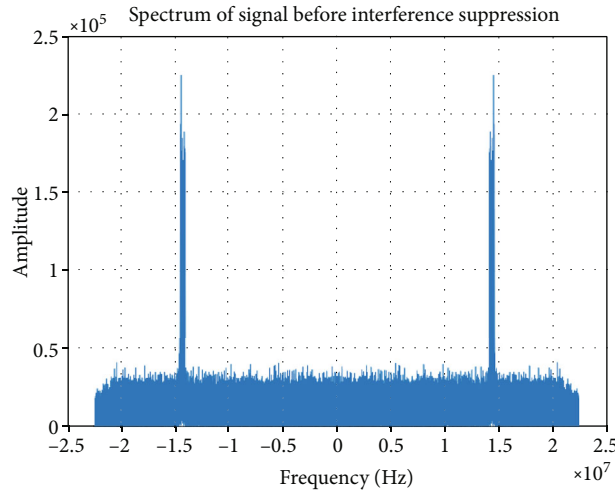


FIGURE 17: Spectrum of signal before interference suppression.

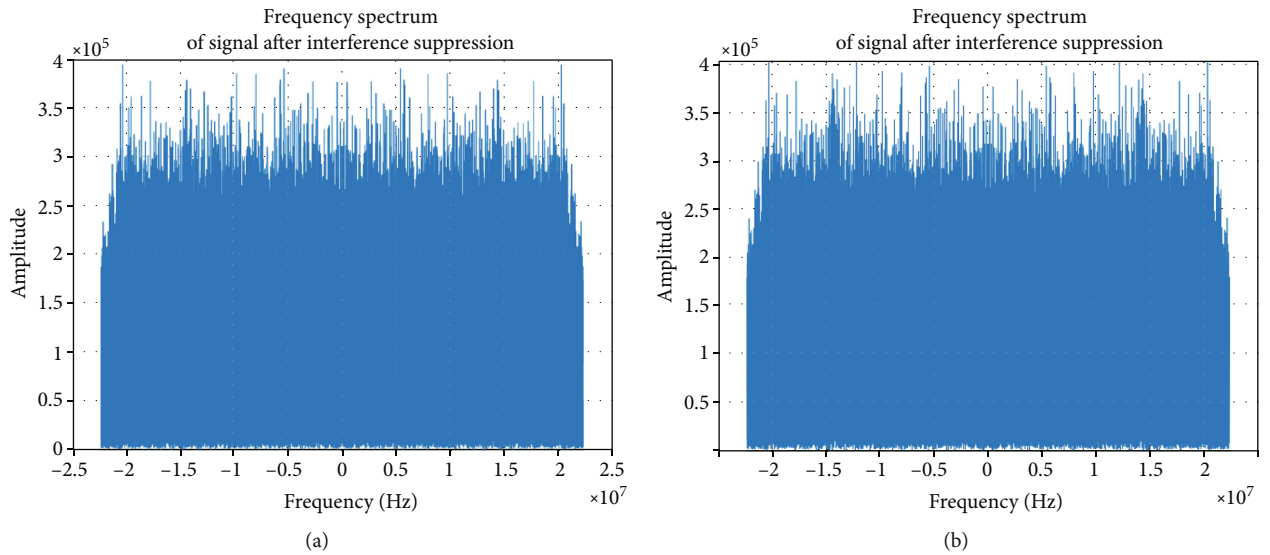


FIGURE 18: Frequency spectrum of signal after interference suppression.

(3) *Experiment 3: Narrowband Interference Suppression Experiments for BOC (14, 2) Modulated Signals.* Because of the different signal system, the main lobe of BOC (14, 2) is not on the central frequency; so, the frequency point of interference signal is not at the frequency point of the signal center. The interference frequency is 1589.42 MHz by signal generator, 0.4 MHz bandwidth, SNR for narrowband interference signal

is 20 dB, coupled by a coupler and the original navigation signal, after the acquisition device sends its data to the workstation software receiver, and using the method proposed in this paper to suppress narrowband interference, interference suppression, the navigation signal spectrum, capture diagram, constellation diagram, and navigation chart is shown as follows.



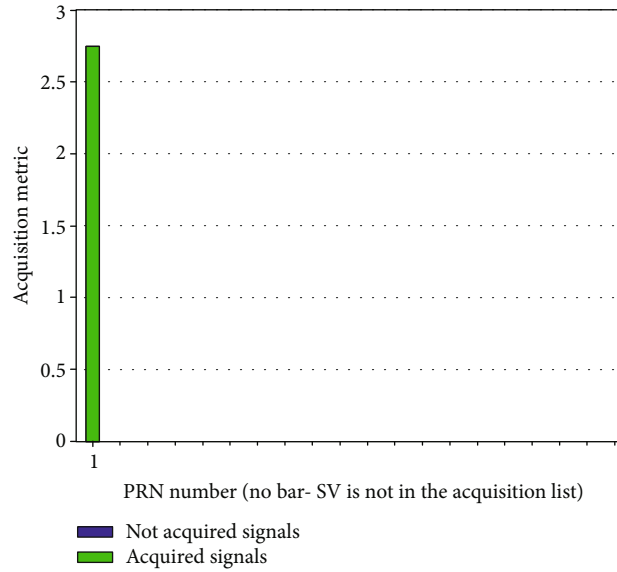


FIGURE 19: Capture plots before interference suppression.

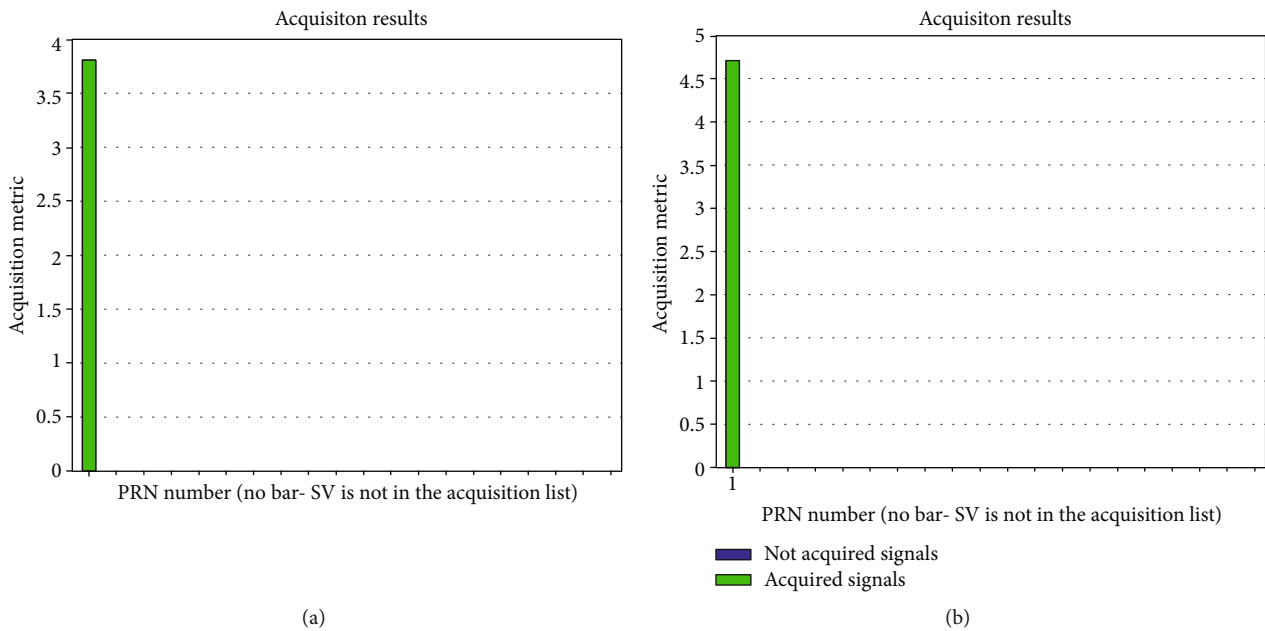


FIGURE 20: Capture plots after interference suppression.

The spectrum before and after narrowband interference suppression is as follows:

As can be seen from Figure 17, due to the influence of narrowband interference, the original navigation signal spectrum in the signal bandwidth has a very narrow interference peak. (a) and (b) are the time-domain filtering and the frequency domain filtered spectrum, respectively, after filtering the navigation method, the frequency domain filtering and the frequency domain filtering process, as shown in Figure 18. The spectrum of the signal has been significantly

improved, from its spectrum can be clearly seen narrowband interference is basically suppressed.

The capture chart before and after narrowband interference suppression is shown below.

As can be seen from Figure 19, signal superimposed narrow-band interference can capture the signal, but its performance was weak, and then compare the signal after the time domain and frequency domain filtering after the capture of Figure 20, and Figure 20(a) and 20(b) are time-domain filtering and frequency domain filtering, respectively. After the

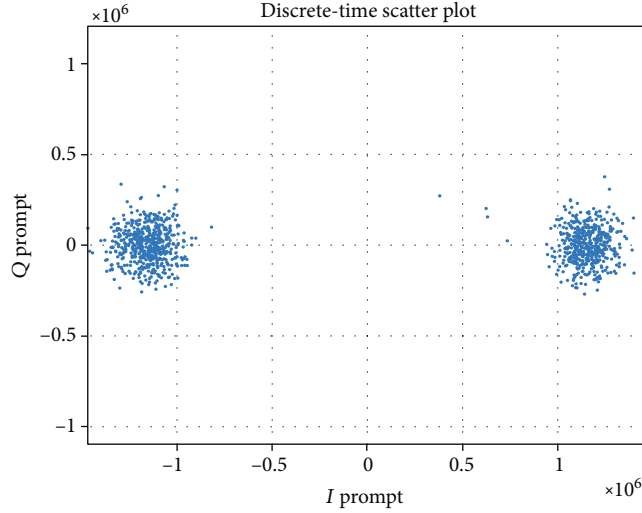


FIGURE 21: Signal constellation before interference suppression.

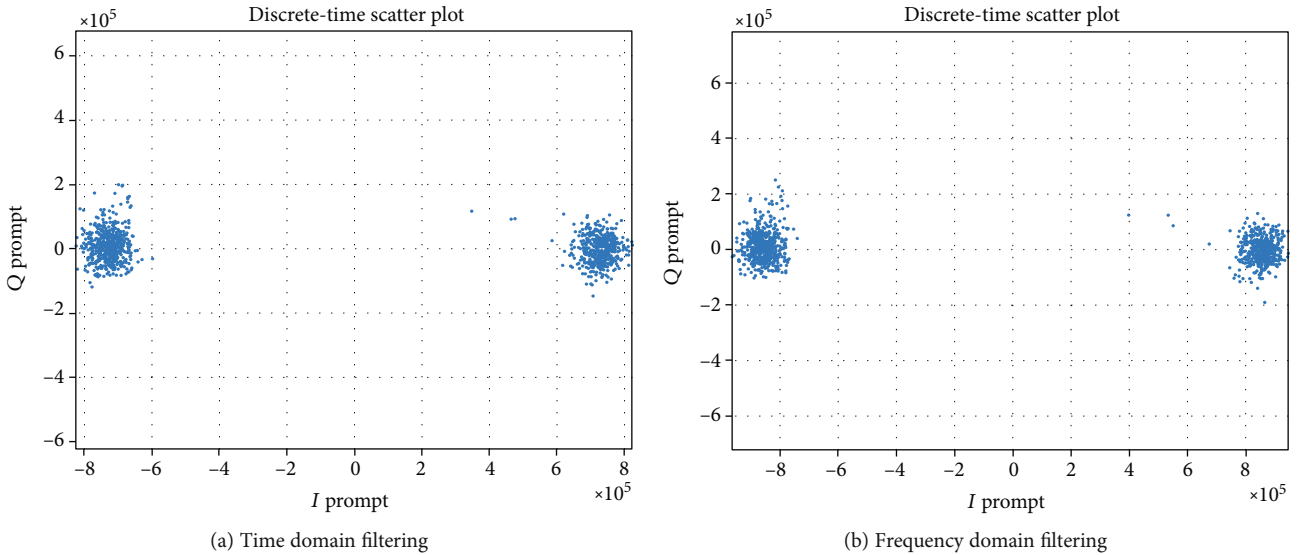


FIGURE 22: Signal constellation after interference suppression.

narrowband interference suppression algorithm is processed, the capture performance of the signal is improved obviously, which indicates that the narrowband interference suppression has achieved the purpose of suppressing interference.

The constellation diagram and navigation message diagram before and after narrowband interference suppression are shown below.

It can be seen from Figures 21–25 that the tracking signal quality is improved, and the tracking performance of the signal is improved when the interference suppression algorithm is added. It can be seen that the interference suppression capability of the frequency domain filtering algorithm is stronger than that of the time domain filtering algorithm. The validity of the applied filtering algorithm is proved.

The interference signal with the interference ratio of 20 dB is added to the original navigation signal, and the ranging accuracy and the carrier-to-noise ratio before and after the interference suppression are obtained by using the two algorithms, respectively.

It is obvious from the above Table 3 that the accuracy of the ranging is increased from 4.456294 to 4.466639, and the carrier-to-noise ratio is increased from 48.748927 dB to 52.759590 dB and 53.987394 dB, respectively, after filtering the signal with narrowband interference. It is shown that the narrowband interference suppression algorithm proposed in this paper has a good effect on the narrowband interference in the signal. At the same time, it can be seen that the frequency domain filtering algorithm has better effect on narrowband interference.

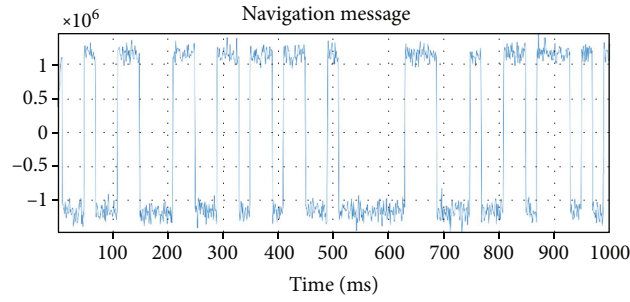


FIGURE 23: Navigation message diagram before interference suppression.

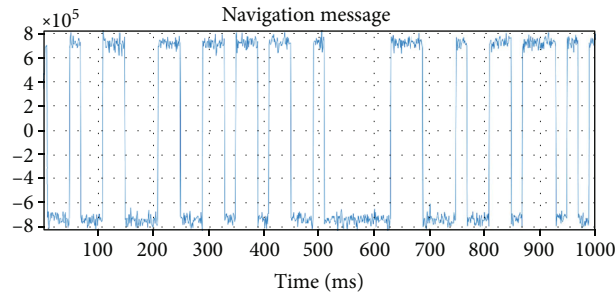


FIGURE 24: Navigation message diagram with the time domain filtering algorithm.

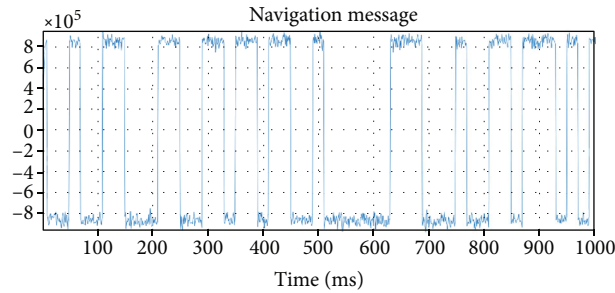


FIGURE 25: Navigation message diagram in the frequency domain filtering algorithm.

TABLE 3: Records of experimental data.

Algorithm	SIR (dB)	Ranging accuracy	C/N (dB)
Interference free suppression algorithm	20	8.645206	48.748927
LMS filtering algorithm in time domain	20	4.986294	52.759590
Frequency domain block LMS algorithm	20	4.466639	53.987394

## 5. Conclusions

Aiming at the suppression of narrowband interference, an improved time domain adaptive algorithm and frequency domain block step size LMS algorithm are proposed based on the analysis of the conventional time-domain adaptive LMS algorithm. The simulation results show that the two algorithms narrowband interference can be effectively suppressed, thereby improving the antijamming performance of satellite

navigation receivers. The innovation of this paper is that when the narrowband interference is suppressed, the conventional time domain adaptive algorithm is improved and applied to the actual engineering. The simulation and experiment are proved to be effective and feasible.

## Data Availability

No data were used to support this study.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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