Research Article

Hui Xie, Yatao Wang, Zhiliang Gao, Bibhu Prasad Ganthia*, and Chinh V Truong

Research on frequency parameter detection of frequency shifted track circuit based on nonlinear algorithm

<https://doi.org/10.1515/nleng-2021-0050>

Received Aug 29, 2021; accepted Dec 02, 2021

Abstract: The basic task of railway signal work is to ensure safe and smooth transportation, improve transportation capacity, and improve transportation conditions and quality. Since it carries important information and control technology; it must be characterized by high security and high reliability. To address the aforementioned issues, this study uses a nonlinear technique to provide high-precision real-time detection of frequency shift signal parameters, based on an investigation of the sources of spectrum leakage in the FFT transformation. It not only reduces the sampling time but also the computation time when compared to the nonlinear method. This paper presents a frequency shift track circuit parameter based on nonlinear algorithm, studies the application of frequency shift signal parameter detection based on nonlinear algorithm, and simulates it with MATLAB. The experimental results show that the errors of center frequency, low frequency, and frequency offset are distributed in the range of ± 0.05 Hz, ± 0.005 Hz and ± 0.15 Hz, respectively, which meet the parameters of frequency shift signal. The algorithm can meet the requirement of technical indexes and shorten the sampling time, which provides a theoretical basis for the design of the real-time frequency shift signal parameter tester.

Keywords: Frequency shift signal; frequency resolution; nonlinear algorithm

1 Introduction

Railway plays an essential role in the development of the national economy. The main function of railway signals is to ensure traffic safety and improve transportation capacity. The switch of safety signals at any moment can cause a disastrous situation and it's a matter of many lives and the government property. Since, with the rapid increase in population, the railway tracks are too busy and proper functioning of the track signals is the matter of priority. Various sensors operated with the artificial intelligence tools and data analytics has been employed in train operations to improve the efficiency of operation. Many algorithms are proposed for the allocation and optimization [1, 2]. To ensure driving safety, the relevant operation parameters of the track circuit need to be detected regularly in daily maintenance. However, the current track circuit mainly uses frequency shift signal as control information, so timely understanding the status of the frequency shift signal of track circuit can provide great convenience for line maintenance work. In the railway equipment system, the railway signal carries all kinds of information states [3]. It controls the running direction, running line, running speed, and running interval of the train and shows the running state and line of the train. Railway signal equipment is an important technical equipment to ensure the safety of train operation and improve transport efficiency [4]. It can control the safe operation of trains by sending various control information to trains, thus, it effectively ensures the smooth and orderly operation of railway transportation dispatching and command, improves the railway transportation management level on the one hand, and improves the safety level of train operation on the other hand, the safety of people's lives and property has been effectively guaranteed [5]. Since the 1980s, with the continuous emergence and development of new technologies, modern communication technology, microelectronics, computer control, and other advanced technologies have been widely used in railway signals, it integrates the process of information collection and processing with the control, which makes the modernization

***Corresponding Author: Bibhu Prasad Ganthia:** Electrical Engineering Department, IGIT Sarang, Odisha, India; Email: jb.bibhu@gmail.com

Hui Xie: School of Transportation and Management of Zhengzhou Railway Vocational & Technical College, Zhengzhou, 451460, China

Yatao Wang: Operation Branch of Zhengzhou Metro Group Co., Ltd. Zhengzhou, 450000, China

Zhiliang Gao: Vehicle Department of the Zhengzhou Zhongjian Shen RailTransit Co., Ltd, Zhengzhou, 450000, China

Chinh V Truong: Industrial University of Ho Chi Minh City, Vietnam

of railway transportation production and operation management get great development. The basic task of railway signal work is to ensure safe and smooth transportation, improve transportation capacity, and improve transportation conditions and quality. As an important information transmission and control technology; it must be characterized by high security and high reliability [6].

Moreover, various machine learning based techniques for railway signal management has been under study. Machine learning has earned major advances in recent years in almost every sector. The objective of these platforms is to control the traffic management, safety and ensuring the real time performance by diagnosing the faults in the signals. It will ensure sustainability for longer use [7, 8]. At present, many research on the detection methods of frequency shift signal parameters use Zoom-FFT to refine the spectrum, hoping to achieve high frequency resolution [9]. However, under the actual engineering conditions, this method increases the sampling time while improving the frequency resolution, which can not meet the real-time requirements of the test instrument [10]. The detection of frequency shift signal parameters is divided into time domain detection and frequency domain detection [11]. The frequency domain detection method is widely studied because of its strong antiinterference ability compared with the time domain detection method [12]. High frequency resolution can be achieved by using nonlinear spectrum refinement. However, in practical engineering, the method increases the sampling time while improving the frequency resolution, so it can not meet the real-time requirements of the instrument. The linear frequency modulated Z transform (nonlinear algorithm) algorithm can improve the frequency resolution and shorten the sampling time, but it increases the system memory and computational complexity. To solve the above problems, based on the analysis of the causes of spectrum leakage in the FFT transformation, this study adopts a nonlinear algorithm to realize the high-precision real-time detection of frequency shift signal parameters. Compared with the nonlinear algorithm, it not only shortens the sampling time, but also reduces the computation. Zheng *et al.* established guard models to protect track circuits from interference [13]. Firstly, the parameters of the protector model are calculated according to the circuit resonance principle [14]. Secondly, according to the theory of transmission line, the four-terminal network model of track circuit in normal state is established, and the transmission equation is derived [15, 16]. Thirdly, it simulates the track voltage and establishes an experimental platform to verify the model. Finally, the transmission equation of the protector is derived and the variation of the rail voltage is analyzed [17]. The results show that the

tuning fault has a significant effect on the track voltage [18]. However, the installation of the protector can effectively reduce the impact and does not bear the normal operation and maintenance of the track circuit, which significantly improves the protection ability of the track circuit with tuning zone faults [19]. Xu *et al.* proposed a new method based on the combination of singular value decomposition (SVD) filtering and least squares parameter invariant signal technique (LTS-ESPRIT) to detect faults in the stator of doubly fed wind turbines [20]. The stator current signals and rotor current signals were simulated in the form of stator interturn short circuit faults and TLS-ESPRIT performance tests were performed [21]. The results show that TLS-ESPRIT still has the high frequency resolution of short time signals with high frequency resolution and can accurately estimate the frequency of each part of the stator current [22]. This method can effectively shorten the rhythm of the sampled signal, and its performance of parameter estimation is also superior [23].

On the basis of the present research, the application of frequency parameter detection of frequency shifting track circuit based on nonlinear algorithm is studied [24]. The simulation results show that the upper frequency and lower frequency, low frequency modulation frequency, and carrier frequency of frequency shift signal can be demodulated accurately, the parameters of domestic 18 information types, and ZPW-2000 frequency shift signal can be used in a short sampling time, meeting the error index, accurate and high-precision detection. The contradiction that the frequency resolution is inversely proportional to the sampling time is well solved. Theoretically, it is proved that this algorithm is a feasible demodulation method for the frequency shift signal of track circuit. As a time-frequency analysis method, this algorithm enriches the detection method of railway signals [24, 25].

The aforementioned section discusses the introduction of the manuscript. Research methodology and principals and application of the research algorithms have been discussed in Section 2. Result analyses have been covered in Section 3. At last, Section 4 concludes the paperwork.

The present paperwork proposes a nonlinear algorithm in which frequency shifting track circuit has been studied to shorten the time of signal processing. The simulation results were analyzed for different frequency range and error range was observed. It was proved that this algorithm is feasible for the frequency shift of track circuit and can be applicable in typical railway signals.

2 Research method

The characteristics along with requirements for the frequency shift parameter detection have been discussed briefly. The principal and application of nonlinear algorithm has also been mentioned.

2.1 Definition and spectral characteristics of frequency shift signals

China's track circuit system is mainly frequency shifting track circuit, including the domestic 18 information frequency shifting track circuit and the introduction of French UM71 and the localization of ZPW-2000 frequency shifting track circuit. Both of them take frequency as a parameter and use the frequency modulation method to transfer low frequency information to higher carrier frequencies, to form a frequency modulation signal with constant amplitude and periodic change of frequency with the amplitude of low frequency signal, and realize the information transmission. The time-domain expression of the frequency shift signal is:

$$S(t) = A_0 \cos \theta(t) = A_0 \cos [\omega_0 t + g(t)] \quad (1)$$

Among them, $g(t) = \int k f(t) dt$, is a trigonometric periodic function of period T , A_0 is the amplitude of the frequency shift signal, $\theta(t)$ is the instantaneous phase of the frequency shift signal, Ω_0 is the angular frequency of carrier frequency, $f(t)$ represents A low-frequency modulated square wave signal, k is the coefficient, representing the sensitivity of the frequency shifter, in Hz/V. Formula (1) is expressed by Fourier series in the complex form, and the spectrum expression of the frequency shift signal can be obtained after simplification, as shown in Formula (2):

$$S(t) = \frac{A_0}{\pi} \sum_{n=-\infty}^{\infty} \frac{1}{m^2 - n^2} \left[\begin{array}{l} (m+n) \left(\sin m \frac{\pi}{2} \cos n \frac{\pi}{2} \right. \\ \left. - \cos m \frac{\pi}{2} \sin n \frac{\pi}{2} \right) \\ + (-1)^n (m-n) \left(\sin m \frac{\pi}{2} \cos n \frac{\pi}{2} \right. \\ \left. + \cos m \frac{\pi}{2} \sin n \frac{\pi}{2} \right) \end{array} \right] \times \cos(\Omega_0 + n\Omega_1)t \quad (2)$$

Type, Ω_1 is the fundamental frequency, m is the frequency shift index ($m = \Delta f/f_1$), n is the edge frequency, $n = \dots -2, -1, 0, 1, 2, \dots$. At present, the frequency shifting track circuit system used in China's main railways mainly includes domestic 18 information frequency shifting track circuit and ZPW-2000 non-insulating frequency shifting track circuit (imported from France UM71 and made domestically),

phase continuous keying frequency shift signal (FSK) is used in the frequency shift signals of the two track circuits. Domestic 18 information frequency shift signals, frequency offset is ± 55 Hz, the center frequency is 550, 650, 750, and 850 Hz, 4, a total of 18 low frequencies, including 7, 8, 8.5, etc. ZPW-2000 frequency shift signal, frequency offset is ± 11 Hz, center frequency is 1700, 2000, 2300, and 2600 Hz, 4, low frequency increases from 10.3 Hz to 29 Hz according to 1.1 Hz arithmetic progression, a total of 18 [22]. According to the above discussion on frequency shift signal spectrum characteristics, the theoretical amplitude spectra of frequency shift signals of the two types of track circuits can be obtained, as shown in Figure 1 and Figure 2:

Figure 1: Theoretical amplitude spectrum of domestic 18 information frequency shift signals

Figure 2: Theoretical amplitude spectrum of ZPW-2000 frequency shift signal

Through analysis, the parameters obtained from the frequency spectrum of the frequency shift signal are as follows:

1. Signal center frequency. For the domestically 18 information frequency shift signal, the frequency corresponding to the two edge frequencies with the largest

peak value is summed and then its average value is calculated. For the ZPW-2000 frequency shift signal, the frequency with the largest amplitude in the spectrum graph is the center frequency.

2. Low frequency modulation frequency f_1 of the signal. The absolute value of the difference between the frequencies of two adjacent edge frequencies.
3. Frequency offset value. Calculate by formula $\Delta f = f_1 \cdot m$. For the domestic 18 information frequency shift signals, the frequency shift index m is calculated by determining the ratio of n_1 and n_2 on the left and right sides of the maximum peak value, namely, the amplitude at the same odd or even subedge frequency, and then we plug in $\Delta f = f_1 \cdot m$ to get the frequency offset.

2.2 Requirements for frequency shift signal parameter detection

The main detection parameters of track circuit frequency shift signal to achieve the technical indexes are as follows: The center frequency of the signal: the discrimination force of frequency display is 0.1 Hz, and the error is 0.3 Hz; Signal low frequency modulation frequency: frequency display discrimination force is 0.01 Hz, error is 0.03 Hz; Frequency offset: the discrimination force of frequency display is 0.1 Hz, and the error is 0.3 Hz [16].

2.3 Requirements and difficulties of frequency shift signal parameter detection

The parameters of frequency shift signal include carrier frequency, low frequency, frequency offset, upper, and lower frequency. The above parameters are detected on site and compared with the preset standard value to determine whether the equipment sending the frequency shift signal is working normally. The technical indexes of the test parameters are as follows:

1. Carrier frequency: resolution is 0.1 Hz; error is 0.2 Hz ± 1 resolution.
2. Low frequency: resolution of 0.01 Hz; error of 0.03 Hz ± 1 resolution.
3. Frequency offset: resolution is 0.1 Hz; error is 0.2 Hz ± 1 resolution.
4. Upper and lower edge frequencies: the resolution is 0.1 Hz; the error is 0.2 Hz ± 1 resolution.

When the frequency shift signal is analyzed, the frequency resolution is $df = f_s/N$, where f_s the sampling frequency is, N is the number of sampling points. There are two ways to improve the frequency resolution, one is to increase the number of sampling points N ; second, reduce the sampling frequency f_s . However, the method of increasing sampling points needs to deal with a large amount of data and needs a large amount of storage space, which requires high hardware requirements. However, the method of reducing the sampling frequency will lead to the aliasing of the signal spectrum and cannot guarantee the detection accuracy of the frequency. The sampling time (that is, the length of the signal used $T = N/f_s$), therefore, the frequency resolution is inversely proportional to the sampling time. Increasing the frequency resolution means that the sampling time will increase, which cannot meet the real-time requirements of the test instrument. Therefore, it is necessary to find a way to strike a balance between improving frequency resolution and reducing the sampling time, while the nonlinear algorithm (linear frequency modulation Z transform) method can achieve a higher frequency resolution within a very short sampling time [17].

2.4 Principle and application of nonlinear algorithm

The given signal is $x(n)$, length $n = 0, 1, \dots, N-1$, the length of the transformation $r = 0, 1, \dots, M-1$, and its nonlinear algorithm transformation is:

$$X(z_r) = CZT[x(n)] = \sum_{n=0}^{\mu} x(n) z_r^{-n} = \sum_{n=0}^{\mu} x(n) A^{-n} W^{nr} \quad (3)$$

Further transformations can be obtained,

$$\begin{aligned} X(z_r) &= W^{r^2/2} \sum_{n=0}^{N-1} g(n) h(r-n) \\ &= W^{r^2/2} [g(r) * h(r)] W^{r^2/2} y(r) \end{aligned} \quad (4)$$

$$g(n) = x(n) A^{-n} W^{n^2/2} \quad (5)$$

$$h(n) = W^{-n^2/2} \quad (6)$$

$$y(r) = g(r) * h(r) = \sum_{n=0}^{N-1} g(n) W^{-(r-n)^2/2} \quad (7)$$

The calculation steps of the detection algorithm are as follows:

1. The sampled frequency shift signal $x(n)$ is calculated according to Eq. (5) $g(n)$, $n = 0, 1, \dots, N-1$, and then I'm going to zero out $g(n)$ so that the length is L , $L \geq N + M - 1$ the new sequence $g'(n)$ is obtained

$$g'(n) = \begin{cases} g(n) & n = 0, 1, \dots, N-1 \\ 0 & N \leq n \leq L-1 \end{cases} \quad (8)$$

2. Convert $h(n)$ into a new sequence $h'(n)$ of point L

$$h'(n) = \begin{cases} h(n) & 0 \leq n \leq M-1 \\ 0 & M \leq n \leq L-N \\ h(L-n) & L-N+1 \leq n \leq L-1 \end{cases} \quad (9)$$

3. Calculate the DFT of $g'(n)$ and $h'(n)$ respectively, and get $G'(k)$, $H'(k)$
4. Convolve $G'(k)$ and $H'(k)$ to obtain

$$Y'(k) = H'(k) G'(k) \quad (10)$$

5. Take the inverse transformation of $Y'(k)$ to get $y(r)$
6. Let us take the first M points of $y(r)$. And then I multiply $W^{r^2/2}$ times $y(r)$, the final output is $X(z_r)$, $r = 0, 1, \dots, M-1$.
7. Calculate the carrier frequency and low frequency of the transformed data $X(z_r)$ according to the characteristics of theoretical spectrum analysis. The nonlinear algorithm can be used not only to calculate the Z

transform on the unit circle, but also to calculate the Z transform on any spiral in the Z plane. Of course, only the Z transform on the unit circle is the Fourier transform. Its advantage is that the required starting frequency and frequency resolution can be selected, and there is no limit on the size of N and M when making nonlinear algorithm, just want $L \geq N + M - 1$, and I take L to an integer power of 2. In addition, the nonlinear algorithm transform also has the function of filtering, because it only gets the spectrum of the frequency of interest, if the signal is mixed with interference signals of power frequency 25 Hz and 50 Hz, it will be filtered out directly outside the spectrum range of concern after transformation by nonlinear algorithm [18].

3 Result analyses

3.1 Simulation example of algorithm

Taking the domestic 18 information system frequency shift signal as the object, under the MATLAB environment, with the center frequency $f_0 = 550$ Hz, deviation $\Delta f = 55$ Hz, 18 modulated low frequencies were taken as examples for simulation analysis, in which the sampling frequency was 2560 Hz, the number of sampling points is 2048, that is,

Table 1: Simulation results of FFT spectrum correction algorithm when the center frequency is 550 Hz

The center frequency is calculated	Error	Low-frequency calculation value	Error	Frequency offset calculation value	Error
550.0010	0.0010	7	-6.69E-06	55.0018	0.0018
549.9991	-0.0009	8	-9.65E-06	55.0037	0.0037
550.0004	0.0004	8.5	6.75E-06	55.0011	0.0011
550.0010	0.0010	9	1.90E-05	55.0001	9.6E-05
550.0002	0.0002	9.5	-3.54E-05	54.9995	-0.0050
550.0004	0.0004	10.9998	-0.0002	55.0109	0.0109
549.9994	-0.0006	12.5	5.10E-06	54.9824	-0.0176
550	-7.48E-05	13.5	-1.71E-05	54.9979	-0.0021
550	-8.48E-05	15	-8.82E-05	54.9998	-0.0003
550	-3.56E-05	16.5	8.43E-05	55.007	0.0070
550.0001	0.0001	17.4999	-0.0001	54.9948	-0.0052
550.0001	0.0001	18.5	2.63E-06	54.9896	-0.0104
549.9997	-0.0003	19.9999	-0.0001	54.9843	-0.0157
550	-4.65E-05	21.5	1.07E-05	55.001	0.0010
549.9996	-0.0004	22.5	-6.81E-05	54.9951	-0.0049
550	-7.39E-05	23.5001	0.0001	55.0084	0.0084
549.9996	-0.0004	24.4998	-0.0002	55.0128	0.0128
550.0001	0.0001	26.0001	0.0001	54.9964	-0.0036

the frequency resolution is 1.25 Hz, and the sampling time is 0.8s. The simulation results are shown in Table 1. The calculation errors of all parameters meet the requirement of indexes. Due to space limitation, the other three groups of simulation results of domestic 18 information system and four groups of simulation results of ZPW-2000 system are not given.

3.2 Feasibility analysis of algorithm

According to “railway signal maintenance rules”, the main technical indexes of domestic 18 information and ZPW-2000 frequency shifting automatic block equipment frequency shifting cabinet transmission box should meet certain requirements. To facilitate the feasibility analysis, the indexes of the two types of frequency shifter cabinets are unified and certain deviation values are added to make the parameters meet the following requirements, as shown in Table 2.

In the verification program, the five-layer cycle is used to achieve. First layer, center frequency from 550 Hz, 650 Hz, 750 Hz to 850 Hz (or 1700 Hz, 2300 Hz to 260 Hz or 2000 Hz); In the second layer, the center frequency increases by 5 Hz in the range of $f_0 \pm 50$ Hz. The third layer, low frequency modulation frequency from 7 Hz, 8 Hz, ..., 26 Hz (or 10.3 Hz, 11.4 Hz, ..., 29 Hz); In the fourth layer, the low frequency increases by 0.05 Hz in the range of $f_1 \pm 0.5$ Hz. At the fifth layer, the frequency offset increases at 0.5 Hz intervals within the $\Delta f \pm 0.5$ Hz range. Under the above

conditions, the total number of cycles is $4 \times 21 \times 18 \times 21 \times 21 = 666792$. Through MATLAB simulation, the statistical results of the calculated values of each parameter are shown in Table 3, Table 4, and Table 5. Among them, frequency refers to the number of errors of the calculated values of each parameter falling within the allowable error range; frequency is the ratio of frequency to the total number of experiments.

The simulation results show that the upper frequency and lower frequency, low frequency modulation frequency, and carrier frequency of frequency shift signal can be demodulated accurately, the parameters of domestic 18 information types, and ZPW-2000 frequency shift signal can be used in a short sampling time, meeting the error index, accurate and high-precision detection. The contradiction that the frequency resolution is inversely proportional to the sampling time is well solved. Theoretically, it is proved that this algorithm is a feasible demodulation method for the frequency shift signal of track circuit. As a time-frequency analysis method, this algorithm enriches the detection method of railway signals.

The proposed nonlinear algorithm based on frequency shift track circuit parameter proved out to be safe for smooth transportation with quality and reliability. Central frequency, low frequency and frequency deviation was observed for deviation range and experimental data was analyzed. According to the experimental data of domestic 18 information types and ZPW-2000 frequency shift signals (as shown in Table 3, Table 4, and Table 5), it can be seen that the errors of the calculated values of center frequency, low frequency and frequency offset are distributed within the range of ± 0.05 Hz, ± 0.005 Hz and ± 0.15 Hz, respectively, which all meet the detection indexes of frequency shift signal parameters.

Table 2: Technical indexes of two types of frequency shifter transmission boxes

Project	Deviation ranged (unit: Hz)
Center frequency	± 50 (interval 5)
Low frequency	± 0.5 (interval 0.05)
Frequency deviation	± 5 (interval 0.5)

Table 3: Statistical results of 666,792 experiments of low frequency calculation error of two types of frequency shift signals

Allowable error range for low frequency	Domestic 18 information type		Type ZPW-2000	
	Frequency	Frequency	Frequency	Frequency
$[-0.03, -0.015]$	0	0	0	0
$[-0.015, -0.01]$	0	0	0	0
$[-0.01, -0.005]$	0	0	0	0
$[-0.005, 0]$	311046	0.4665	265847	0.3987
$[0, 0.005]$	355746	0.5335	400918	0.6013
$[0.005, 0.01]$	0	0	0	0
$[0.01, 0.015]$	0	0	0	0
$[0.015, 0.03]$	0	0	0	0

Table 4: Statistical results of 666,792 experiments of the error of the calculated values of frequency and frequency offset of domestic 18 informational centers

Allowable error interval of frequency offset	Center frequency		Deviation	
	Frequency	Frequency	Frequency	Frequency
[-0.3,-0.25]	0	0	0	0
[-0.25,-0.2]	0	0	0	0
[-0.2,-0.15]	0	0	0	0
[-0.15,-0.1]	0	0	0	0
[-0.1,-0.05]	0	0	616	0.0009
[-0.05,0]	334331	0.514	327567	0.4913
[0,0.05]	332461	0.4986	337866	0.5067
[0.05,0.1]	0	0	680	0.0010
[0.1,0.15]	0	0	63	0.00009
[0.15,0.2]	0	0	0	0
[0.2,0.25]	0	0	0	0
[0.25,0.3]	0	0	0	0

Table 5: Statistical results of 666,792 experiments of ZPW-2000 center frequency and frequency offset calculation errors

Allowable error interval of frequency offset	Center frequency		Deviation	
	Frequency	Frequency	Frequency	Frequency
[-0.3,-0.25]	0	0	0	0
[-0.25,-0.2]	0	0	0	0
[-0.2,-0.15]	0	0	6	9.0E-06
[-0.15,-0.1]	0	0	52	0.00008
[-0.1,-0.05]	0	0	585	0.0009
[-0.05,0]	318392	0.4775	311969	0.4679
[0,0.05]	348400	0.5225	353330	0.5299
[0.05,0.1]	0	0	795	0.0012
[0.1,0.15]	0	0	55	0.00008
[0.15,0.2]	0	0	0	0
[0.2,0.25]	0	0	0	0
[0.25,0.3]	0	0	0	0

4 Conclusions

By analyzing the frequency spectrum characteristics of track circuit frequency shift signal, the application of frequency parameter detection of track circuit frequency shift based on nonlinear algorithm is studied. The simulation result shows that can be accurately the demodulation frequency, shift signal frequency and next frequency, low frequency modulation frequency and carrier frequency, the parameter of technical indicators have reached the frequency detection, domestic 18 informational and ZPW - 2000 type two kinds of frequency shift signal parameters in a shorter sampling time, meet the error indicators, accurate, high precision. The experimental findings further reveal that the

errors of centre frequency, low frequency, and frequency offset are spread in the ranges of 0.05 Hz, 0.005 Hz, and 0.15 Hz, respectively, which fulfills the frequency shift signal criteria. The paradox of frequency resolution being inversely related to sampling time is satisfactorily resolved. This approach is shown to be a plausible demodulation method for the frequency shift signal of a track circuit in theory. This technique increases the identification method of railway signals by using a time-frequency analysis method and proved out to be reliable and fast for transmitting the signals.

Compliance with Ethical Standards: The authors declare that they have no conflict of interest in place and comply with international, national, and/or institutional standards

on research involving Human Participants and/or animals and Informed Consent.

Funding information: The authors state no funding involved.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of interest: The authors state no conflict of interest.

References

- [1] Kumar P, Kansal L, Gaba GS, Mounir M, Sharma A, Singh PK. Impact of peak to average power ratio reduction techniques on generalized frequency division multiplexing for 5th generation systems. *Comput Electr Eng.* 2021;95:107386.
- [2] Rastogi G, Sushil R. Cloud computing implementation: Key issues and solutions. 2015 2nd International Conference on Computing for Sustainable Global Development (INDIACom); 2015 March 11-13; New Delhi, India. IEEE, 2015 p. 320-324.
- [3] Boashash B. Estimating and interpreting the instantaneous frequency of a signal. II. Algorithms and applications. *Proc IEEE.* 1992;80(4):540-68.
- [4] Liu N, Aljankawey A, Diduch C, Chang L, Su J. Passive Islanding Detection Approach Based on Tracking the Frequency-Dependent Impedance Change. *IEEE Trans Power Deliv.* 2015;30(6):2570-80.
- [5] Yang Y, Peng ZK, Meng G, Zhang WM. Spline-Kernelled Chirplet Transform for the Analysis of Signals With Time-Varying Frequency and Its Application. *IEEE Trans Ind Electron.* 2012;59(3):1612-21.
- [6] Tang L, Zhao J. Switched threshold-based fault detection for switched nonlinear systems with its application to Chua's circuit system. *IEEE Trans Circuits Syst I Regul Pap.* 2019;66(2):733-41.
- [7] Gupta S, Vyas S, Sharma KP. A Survey on Security for IoT via Machine Learning. 2020 International Conference on Computer Science, Engineering and Applications (ICCSEA); 2020 March 13-14; Gunupur, India. IEEE, 2020 p. 1-5.
- [8] Bhatia V, Kaur S, Sharma K, Rattan P, Jagota V, Kemal MA. Design and simulation of capacitive MEMS switch for Ka band application. *Wirel Commun Mob Comput.* 2021;2021:2021513.
- [9] Chudamani R, Vasudevan K, Ramalingam CS. Real-Time Estimation of Power System Frequency Using Nonlinear Least Squares. *IEEE Trans Power Deliv.* 2009;24(3):1021-8.
- [10] Strunz K, Shintaku R, Gao F. Frequency-Adaptive Network Modeling for Integrative Simulation of Natural and Envelope Waveforms in Power Systems and Circuits. *IEEE Trans Circ Syst I Fundam Theory Appl.* 2006;53(12):2788-803.
- [11] Kamwa I, Grondin R. Fast adaptive scheme for tracking voltage phasor and local frequency in power transmission and distribution systems. *IEEE Trans Power Deliv.* 1992;7(2):789-95.
- [12] Freijedo FD, Doval-Gandoy J, López Ó, Acha E. A Generic Open-Loop Algorithm for Three-Phase Grid Voltage/Current Synchronization With Particular Reference to Phase, Frequency, and Amplitude Estimation. *IEEE Trans Power Electron.* 2009;24(1):94-107.
- [13] Migliorelli C, Alonso B, Romero S, Aparicio J, Van JL, Mañanas MA, et al. SGM: a novel time-frequency algorithm based on unsupervised learning improves high-frequency oscillation detection in epilepsy. *J Neural Eng.* 2020;17(2):026032.
- [14] Tang L, Zhao J. Switched threshold-based fault detection for switched nonlinear systems with its application to Chua's circuit system. *IEEE Trans Circuits Syst I Regul Pap.* 2019;66(2):733-41.
- [15] Hofstetter P, Bakran MM. The two-dimensional short-circuit detection protection for SiC MOSFETs in urban rail transit application. *IEEE Trans Power Electron.* 2019;35(6):5692-701.
- [16] Bhola J, Shabaz M, Dhiman G, Vimal S, Subbulakshmi P, Soni SK. Performance Evaluation of Multilayer Clustering Network Using Distributed Energy Efficient Clustering with Enhanced Threshold Protocol. *Wirel Pers Commun.* 2021 Aug;1-15.
- [17] Jia K, Zhao Q, Feng T, Bi T. Distance protection scheme for dc distribution systems based on the high-frequency characteristics of faults. *IEEE Trans Power Deliv.* 2020;35(1):234-43.
- [18] Feng D, Wang X, Zhang B. A frequency-domain quasi-newton-based biparameter synchronous imaging scheme for ground-penetrating radar with applications in full waveform inversion. *IEEE Trans Geosci Remote Sens.* 2021;59(3):1949-66.
- [19] Schoukens M, Tóth R. Frequency response functions of linear parameter-varying systems. *IFAC-PapersOnLine.* 2019;52(28):32-7.
- [20] Shang H, Du Z, Gao N, Li J, Zhang, Z. Parameter analysis of tunable diode laser absorption spectroscopy based on spectral frequency characteristics. *Guang Pu Xue Yu Guang Pu Fen Xi.* 2019;39(11):3359-3364.
- [21] Dou C, Zheng L, Wang W, Shabaz M. Evaluation of Urban Environmental and Economic Coordination Based on Discrete Mathematical Model. *Math Probl Eng.* 2021;2021:1-11.
- [22] Zheng Y, Shu Z, Gao S. Research on protection of tuning area equipment disconnection in the Zpw-2000a track circuit. *Chin J Electr Eng.* 2021;7(1):106-17.
- [23] Wang B, Yao X, Jiang Y, Sun C, Shabaz M. Design of a Real-Time Monitoring System for Smoke and Dust in Thermal Power Plants Based on Improved Genetic Algorithm. *J Healthc Eng.* 2021 Jul;2021:7212567.
- [24] Boqiang X, Zehui, & Zheng. (2019). svd filtering and Tls-esprit algorithm based on stator fault characteristic detection of a doubly fed induction generator. *J Eng (Stevenage).* 2019;(18):5193-6.
- [25] Sun Y, Li H, Shabaz M, Sharma A. Research on building truss design based on particle swarm intelligence optimization algorithm. *Int J Syst Assur Eng Manag.* 2021. <https://doi.org/10.1007/s13198-021-01192-x>.
- [26] Bhola J, Soni S, Cheema GK. Genetic algorithm-based optimized leach protocol for energy efficient wireless sensor networks. *J Ambient Intell Humaniz Comput.* 2020;11(3):1281-8.