Int. J. Electron. Commun. (AEÜ) 93 (2018) 154–162

Contents lists available at ScienceDirect

Int. J. Electron. Commun. (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Regular paper

New insights about interference suppression algorithm based on analog circuits and linear filtering method in ELF communication

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ARTICLE INFO

Keywords:
Extremely-low-frequency communication
Analog circuits
Linear filtering
Subspace method
Joint diagonalization
Interference suppression

ABSTRACT

In order to improve the communication quality in the extremely-low-frequency communication effectively, a kind of new insight based on analog circuits and linear filtering method for interference suppression is proposed, the latter mainly achieves by the joint diagonalization of the correlation matrices. The proposed algorithm takes place the filter coefficients by a linear combination of eigenvectors, the problem of interference suppression is converted into the solution of constructed coordinates. Besides, three kinds of filters are designed based on the mean square error criterion, the derivation process is given in detail, and several performance evaluation indices are also provided. And the derivation results show that the proposed algorithm can become common filters in speech enhancement when the number of chosen eigenvectors is a certain value. Finally, some experiments are performed in a laboratory environment. And the experimental results show that the proposed algorithm can suppress the interference effectively, and the compromise between the number of interference suppression and the degree of signal distortion can be controlled by changing the number of chosen eigenvectors, the proposed algorithm has potential performance gain.

1. Introduction

Extremely-low-frequency (ELF) communication [1] has the characteristics of stable signal transmission, small attenuation and strong anti-interference ability in the water, which can address the issue of long-distance and deep communication. Besides, ELF communication is almost all-weather, full space for reliable communication, which has rather prominent capabilities for hiding communication. However, the radiation efficiency of the antenna in ELF communication is very low. When the magnitude of transmitter power is MW, only a few Watt of radiated power can be obtained, and the received signal is also facing strong background noise in the range of bandwidth, so signal-to-noise ratio (SNR) in ELF communication is very low. Some existing communication technologies can no longer comply with the requirements of ELF communication. Therefore, in order to improve the reliability of ELF communication, the two aspects can be made. It means increasing transmission power and adopting advanced signal processing technology. However, the cost of the former method is extremely high and the effect is not obvious. Therefore, this paper achieves the above requirements by the latter method.

Given that the signal received in the ELF communication is very weak, the ELF magnetic antenna with high sensitivity must be developed in order to enhance the ability to detect the desired signal. The magnetic antenna is mainly composed by inductive coil and magnetic core. Yan [2] proposed two different optimization schemes considering the volume of the coil and the magnetic core. Coillot [3] optimized inductive magnetometer by adopting ferromagnetic cores with different shapes. Besides, Shao used high-resistivity laminated magnetic cores and magnetic flux collectors on both sides of the magnetic core to increase the effective area and the effective magnetic permeability [4]. In this paper, starting from the principle of magnetism measuring of inductive magnetic sensor, magnetic core with higher relative permeability is selected to produce the magnetic antenna with higher sensitivity. In order to prevent the quantization noise from affecting the performance of the receiver, the analog circuit with low power consumption and low noise is designed.

For interference suppression, there are various algorithms, such as linear filtering [5], wavelet analysis [6], empirical mode decomposition [7] and subspace-based method [8]. The linear filtering and subspace-based method are related to the research in this paper. The former is widely used in speech enhancement [9], it passes the received signal composed by the desired signal and the interference, but the interference is attenuated. Besides, based on the mean square error (MSE) criterion, different filters are designed by different cost functions, such

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https://doi.org/10.1016/j.aeue.2018.06.015
Received 26 March 2018; Accepted 6 June 2018

as linear constrain minimum variance (LCMV)[10], minimum variance without distortion response (MVDR) [11], Wiener [12] and tradeoff filter [12]. For subspace-based method, by the joint diagonalization [13], the received signal and the interference can be projected into different subspaces respectively, the interference statistics can then be estimated from the interference subspace without desired signal. And these statistics can be used to clean the received signal subspace subsequently.

In this paper, the problem of the interference suppression is addressed by combining the linear filtering and subspace-based method. The proposed algorithm takes place the filter coefficients by a linear combination of eigenvectors, the idea originates from so-called indirect filter approach [14], wherein the interference is estimated firstly, and the estimated desired signal is obtained by subtracting the estimated interference from the received signal. In the indirect approach, in order to estimate the interference, the output signal-to-interference ratio is minimized based on the MSE criterion. Therefore, the filter coefficient is converted into a linear combination of eigenvectors, which are corresponding to those zero eigenvalues of the correlation matrix of the desired signal. Although, the relation between linear filtering and subspace-based method has been explained earlier [15], a special filter was adopted, such as Wiener filter. It implies that a variety of filters under the unified framework has not been achieved in the ELF communication. Besides, in these papers, the question about controlling the compromise between the amount of interference suppression and the degree of signal distortion has not been explained explicitly. The above problems can be addressed by the proposed method in this paper. A new unified framework was established. Not only various filters can be derived, but also performance of these filters can be assessed fairly. Moreover, the tradeoff between interference suppression and signal distortion can be improved by choosing the number of eigenvectors reasonably. In other words, the above tradeoff can be handled flexibly by the proposed method.

The rest of the paper is organized as follows. In Section 2, the whole model combining analog circuits with linear filtering is given, the magnetic antenna and analog circuits are designed. In Section 3, problem formulation used in this paper is presented briefly. In Section 4, a new framework is estabilished, the proposed method is introduced. A variety of evaluation indices used to quantify the performance of designed filters in Section 5. This is followed by, in Section 6, various optimal filters based on MSE criterion under different cost functions are derived explicitly. In Section 7, some experiments are performed in a laboratory environment, some parameters related to filter and the correlation matrix of the desired signal are analyzed. Finally, some conclusions can be drawn in Section 8.

2. Overall model

The model of proposed algorithm based on analog circuits and linear filtering method is shown in Fig. 1. In view of the weak ELF signal, the optimization design of the magnetic antenna effectively reduces its distributed capacitance and improves its sensitivity. And given that the strong 50 Hz interference and its harmonic components mixed in the ELF signal, the analog circuits are properly designed, which suppress the out-of-band interference effectively. After the process in analog domain is completed, the conversion of the signal from the analog domain to the digital domain is achieved by the data acquisition unit NI-cDAQ 9184. The collected data are dealt with by the proposed algorithm to achieve interference suppression. Finally, the reasonable evaluation index is established to evaluate the performance of the proposed algorithm.

2.1. Magnetic antenna

Magnetic antenna is mainly composed by inductive coil and magnetic core. The quality of the magnetic antenna has great influence on the performance of magnetic sensor. Due to the limited experimental environment (lack of effective shielding device), the noise floor of the magnetic antenna cannot be measured, therefore, the sensitivity of the magnetic antenna can only be qualitatively analyzed. The choice of the magnetic core is crucial to the performance of the magnetic antenna. The ratio of the length to the diameter is proportional to the effective magnetic permeability, and when the above ratio is constant, in order to ensure that the effective magnetic permeability is constant, the initial permeability must be greater than a certain value. Therefore, when magnetic core is chosen, it is necessary to consider two above factors. The magnetic core used in this paper is the nanocrystalline alloy material, which is a new type of soft magnetic material with higher permeability, higher saturation magnetic strength and lower magnetic core loss. Besides, the material has the better performance and lower price compared with other metal soft magnetic material, such as the silicon steel and permalloy.

When producing the magnetic antennas, the motor and reducer are combined as a winding machine, which can achieve automatic winding instead of the manual winding, and the counter is installed on the winding machine to record the number of winding turns automatically. In addition, the segment winding using acrylic clapboard is adopted. In order to make the winding coil firmly fixed on the magnetic core, the produced magnetic antennas are soaked in the varnish for a period of time. The final produced magnetic antenna is shown in Fig. 2. By measuring its self-resonant frequency, it is shown that the segment winding method can reduce the distributed capacitance of the magnetic antenna by an order of magnitude compared to the original direct winding method, which is equivalent to improve the passband quality factor.

2.2. Analog circuits

The role of the preamplifier is to amplify the front weak signal, the key design is to reduce the noise voltage. The preamplifier used in this paper is the AD797 chips. By referring to the instruction of the chips and simulating the noise model, it is shown that the noise of the chips is very low at frequencies below 1 kHz. Therefore, the chip is well suited as a preamplifier.

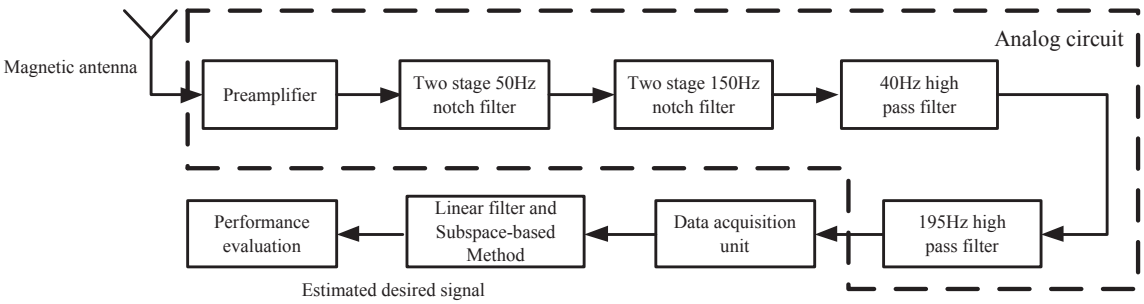

Fig. 1. The whole model diagram of proposed algorithm in ELF communication.