УДК 621.391

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COMPARATIVE ANALYSIS OF THE ACCURACY CHARACTERISTICS OF THE PHASE AND AMPLITUDE DIRECTION FINDING METHODS IN RE-REFLECTION CONDITIONS

The article studies comparative analysis of the accuracy characteristics of the phase and amplitude direction finding methods in re-reflection conditions. Based on the results of simulation, it is concluded that the losses in the accuracy of the phase method reach a few percent up amplitude. Modeling outcomes are listed as follows.

Keywords: *direction finding phase method, direction finding amplitude method, signal intelligence means, circularly disposed antenna array.*

Introduction

The measurement procedure of the angular coordinates by using of signal intelligence (SIGINT) radio emission means is the most time-consuming on instrumental and computational cost challenge relative to the measurement of other time-frequency signal parameters. Known direction finding methods [1–3] used in the SIGINT means and radio monitoring are based on the use of circular antenna arrays (CAR). Estimation of angular coordinates based on algorithmic finding the global extremum of the bivariate function, which is a quadratic form with the matrix of mutual spectra. Such procedures should be considered as the amplitude direction finding methods. Their implementation demands significant computational cost. This constrains the scan velocity of operational frequencies by SIGINT means. In order to overcome this limitation in the article was [4] proposed the phase direction finding method, that allows to reduce the computational cost of signal evaluation procedure.

The method is based on the evaluation of the full phase distribution at the aperture CAR M-element uniform CAR [4]:

$$\Phi_m = \frac{\pi \cdot D}{\lambda} \cdot \cos(\varepsilon) \cdot \cos(\beta - \beta_m), \quad (1)$$

where D – diameter CAR λ – lambda ε, β – elevation angle and bearing angle of emission source; $\beta_m = 2\pi(m-1)/M$ – bearing angle of m element (m=1…M). Evaluation of directional coordinates ε, β from Φ_m in the phase method, performs by using follow formula [4]:

$$\varepsilon = \arccos\left(\frac{\lambda}{\pi \cdot D}\sqrt{\frac{2}{M}\sum \Phi_m^2}\right); \quad (2)$$

$$\beta = \mathrm{arctg}\left[\frac{\sum \Phi_m \cdot \sin(\beta_m)}{\sum \Phi_m \cdot \cos(\beta_m)}\right], \quad (3)$$

where phase summarizing conducts in the 1…M limits.

To calculate direction finding by phase method, is sufficient to estimate the full phases Φ_m. This eliminates the need of finding the extremum of two-dimensional functions. A feature of this method is the need to eliminate ambiguities with the values of the D/λ. As shown in [4], developed phase method has a higher speed in comparison with the amplitude method.

In many practical situations may occur multipath propagation, when along with the direct signal, the input of the direction finder receives a re-reflected signal from local objects. In addition, re-reflection is an essential condition for the propagation in the short-wave frequency range [5]. Availability of the re-reflection reduces the accuracy of the direction finder [2]. There is practical interest is to conduct a comparative analysis of known amplitude methods, with proposed in [4] phase method of direction finding in the presence of re-reflected signals. These issues are the subject of this article.

Main body

A strict comparison of these two methods of direction finding is quite challenging. In this regard, a comparison was carried out by simulation. For this purpose, simulation model was developed in the software environment "Matlab". Note also, that the same reflections affect on accuracy of measurement as well as affect on azimuth and elevation coordinates, therefore in follows, we will consider the issue of this influence only on the accuracy of the azimuth measurements. Imitation of re-reflection signal, performed by summing of the original signal and its copies shifted in time by τ_{shift} and $\varphi_{re\text{-}refl}$ phase with respect to the source and reflections, multiplied by the coefficient K_{refl} (K_{refl} = 0,1..0,5). The magnitude of the correlation coefficient τ_{shift} , defines direct and multipath signals received by the antenna elements. Direction of re-reflected signal in the azimuthal surface relative to the straight signal may have any value. As the noise model a stationary noise process with zero mean and unit variance was used. The same realization of the noise was used in both direction finding methods. As the signal model, record of the real signal from air digital radio communication system was used. To reduce the influence of the receiver's internal noise on the Direction Finding accuracy and highlight the impact of re-reflection, the signal / noise ratio in each element of CAR was set greater than and equal to 15 dB, when the length of the processed selections - 64 counts. The CAR with the number of antenna elements 9 with respect to D/λ = 2, was used by model. The angle of the direct signal locations matched value $\varepsilon_{direct} = 30°$, re-reflected $\varepsilon_{refl} = 0$. Azimuth of direct signal was equal $\beta_{ds} = 180°$. Re-reflected angles of received signal in the azimuthal plane were set within β_{refl} = 1...360° in increments of 1°. We have considered cases of strong and weak correlation of direct and re-reflected signal. It is important to note that a strong correlation characteristic when observed narrowband signals and weak – when observed wideband signals. The degree of correlation also depends on the distance to the reflecting object. Consider the case of strong correlation of the direct and re-reflected signals $\tau_{сдв} = 2 \cdot \Delta t$ (Δt – time step sampling) at a fixed value $K_{refl} = 0.5$, which is close to the maximum possible value. Fig. 1 shows the obtained values of errors of measuring azimuthal coordinate's β_{error} by two methods. The error discrepancies of methods are so small that on the chart, they merge into a single curve.

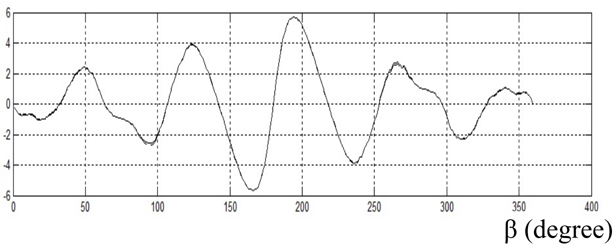

Fig. 1. Errors of both direction finding methods under weak correlation of direct and re-reflected signals ($\tau_{shift} = 2 \cdot \Delta t$)

Error curve on the graph corresponds to both methods, proving that re-reflection has influence on both methods, with the same degree. As can be seen from the graph, the maximum error is a few degrees, which is much higher than the value of the fluctuation error. Maximum number of errors occurs only in certain directions. The value of the root mean square error (RMSE) of direction finding is shown in fig. 1, for amplitude method, it amounted to 2,448°, and for phase method amounted to 2,450°.

To illustrate the differences of methods estimates in fig. 2 showed the magnitude of discrepancy β_{discr} of two methods graphically, the difference between value β_{error} of amplitude method and value β_{error} of phase method.

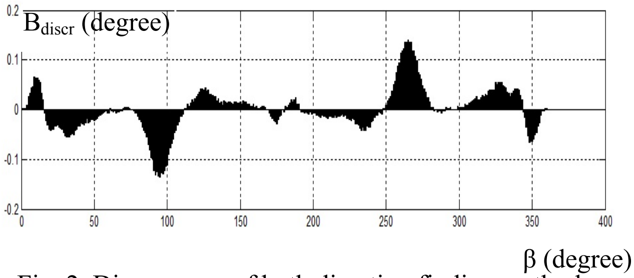

Fig. 2. Discrepancy of both direction finding methods under strong correlation of direct and re-reflected signals ($\tau_{shift} = 2 \cdot \Delta t$)

The graph shows, that discrepancy between these two methods of assessment has a low value, which can be neglected.

It analyzes also the case of weak correlation of direct and multipath signals corresponding to the instructions of $\tau_{shift} = 30 \cdot \Delta t$ at a fixed value $K_{refl} = 0,5 = 0.5$. Fig. 3 shows the values obtained errors β_{error}.

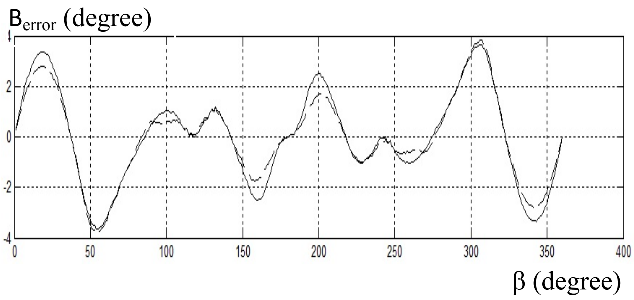

Fig. 3. Errors of both direction finding methods under weak correlation of direct and re-reflected signals ($\tau_{shift} = 30 \cdot \Delta t$)

Here is showed the error of the amplitude method by dashed lines, and proposed method of the direction finding by solid line. The value of RMSE of direction finding is much smaller, than in the previous case, and for the amplitude method amounted 0.65°, and for phase method amounted to 0,81°.

Fig. 4 shows the evaluation discrepancy β_{discr} of the two methods for the values shown in the graph in fig. 3.

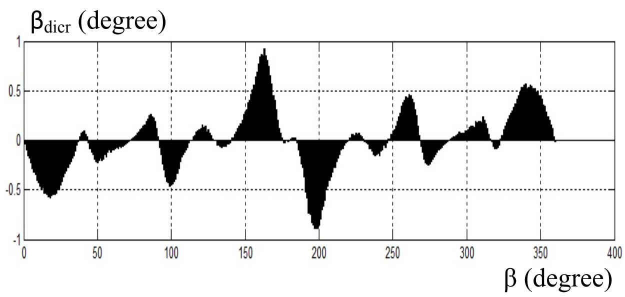

Fig. 4. Discrepancy of both direction finding methods under weak correlation of direct and re-reflected signals ($\tau_{shift} = 30 \cdot \Delta t$)

The graph shows that the discrepancies of estimates are more noticeable here, than in the previous case.

Simulation results have shown that both methods depend on the magnitude of errors τ_{shift} time, but largely on the re-reflection coefficient K_{refl}. Errors dependence from the phase of re-reflected signal is negligible. From these graphs (fig. 1–4) follows conclusion, that under correlation reduction between direct and re-reflected signals, number of measurement errors are reduced as well. With a strong correlation discrepancy between the two methods of assessment is less than one order of magnitude, compared to the case of weak correlation. However, in this case the difference is acceptable value. In this case the one feature was detected. This feature is what – upon increasing ratio D/λ, upon fixed value K_{refl}, the likelihood of abnormal error in the assessment of direction finding in both methods increases as well. Abnormal errors mean errors, which greater than the width of antenna array pattern. Apparently, this is due to an increase levels of CAR lateral lobe with increasing D/λ.

The accuracy of the two methods of direction finding in the presence of 2 to 5 re-reflected signals simultaneously, was evaluated as well. The initial conditions are the same simulation. K_{refl} of re-reflected signal does not exceed 0.5. In this case the loss of RMSE of phase method direction finding increased slightly, however, in this case did not exceed a few percent in relation to the amplitude.

Conclusions

Simulation showed the presence of negligible differences in the degree of influence on the accuracy characteristics of the proposed both phase and amplitude direction finding methods. It gives reason to believe that the phase method is suitable for use in re-reflected conditions and has a higher performance [4]. Reducing the effect of re-reflected signals on the direction finding accuracy is associated with an increase in the spatial selectivity of the antenna by increasing the geometric dimensions of the antenna arrays and reduction of the lateral lobe level [6].

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Надійшла до редколегії 3.11.2016

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ПОРІВНЯЛЬНИЙ АНАЛІЗ ТОЧНІСНИХ ПОКАЗНИКІВ ФАЗОВОГО ТА АМПЛІТУДНОГО МЕТОДІВ ПЕЛЕНГАЦІЇ В ЗАСОБАХ РАДІОРОЗВІДКИ ЗА НАЯВНОСТІ ПЕРЕВІДЗЕРКАЛЕНЬ СИГНАЛІВ

А.В. Кобзєв, М.В. Мурзін, А.П. Осколков, Г.М. Зубрицький

Проводиться порівняльний аналіз точнісних характеристик фазового і амплітудного методів пеленгації в умовах перевідзеркалень. Спираючись на результати імітаційного моделювання, робиться висновок про те, що втрати у точності фазового методу відносно амплітудного складають одиниці процентів. Приводяться результати моделювання.

Ключові слова: *фазовий метод пеленгації, амплітудний метод пеленгації, засоби радіорозвідки, кільцева антенна решітка.*

СРАВНИТЕЛЬНЫЙ АНАЛИЗ ТОЧНОСТНЫХ ПОКАЗАТЕЛЕЙ ФАЗОВОГО И АМПЛИТУДНОГО МЕТОДОВ ПЕЛЕНГАЦИИ В СРЕДСТВАХ РАДИОРАЗВЕДКИ ПРИ ПЕРЕОТРАЖЕНИЯХ СИГНАЛОВ

А.В. Кобзев, М.В. Мурзин, А.П. Осколков, Г.Н. Зубрицкий

Проводится сравнительный анализ точностных характеристик фазового и амплитудного методов пеленгации в условиях переотражений. Опираясь на результаты имитационного моделирования, делается вывод о том, что потери в точности фазового метода относительно амплитудного составляют единицы процентов. Приводятся результаты моделирования.

Ключевые слова: *фазовый метод пеленгации, амплитудный метод пеленгации, средства радиоразведки, кольцевая антенная решетка.*