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COMPARISON OF TWO OPTIONS FOR BUILDING THREE-COORDINATE ELECTRONIC INTELLIGENCE STATIONS

*The **subject–coordinate** measurement methods in ground electronic intelligence (ELINT) stations. The **goal** is to conduct a comparative analysis of two options for the composition ground ELINT stations in terms of accuracy of measuring coordinate information. The **tasks** to be solved are as follows: assessing the accuracy of determining the coordinates of the time difference of arrival method (TDOAM) and hybrid method (HM); obtaining analytical ratios for estimating the root-mean-square error (RMSE) of the accuracy of measuring the altitude of radio emission sources (RES) of these methods; on the basis of the obtained estimates and analytical ratios, a comparative analysis of the methods, under conditions where the accuracy of the coordinate information obtained by both methods is commensurate; and development of recommendations regarding the practical application of HM coordinate measurements. The **methods** used are: the theory of measurements and the theory of evaluation of coordinate information. The following **results** were obtained: a comparative analysis of the TDOAM and HM was performed according to the RMSE of the determination of plane coordinates and the altitude of the RES. The accuracy assessment was performed in a known way, based on the linearization of the functional dependence between the measured primary parameters (range differences, elevation angle) and spatial coordinates by expanding in a Taylor series with the deduction of the first two terms of the series. Calculations have shown that the presence of the third side station has very little effect on the accuracy of determining plane coordinates. Significant differences appear only in the results of estimating the RMSE of the RES altitude. To compare the methods, analytical relationships were obtained for estimating the RMSE of the altitude measurement. The condition is determined under which the accuracy of determining the altitude for the HM is not worse than that for the TDOAM (the accuracy is the same). Starting from this value and further, when using the HM, the altitude is determined more accurately. **Conclusions**. An HM of high-precision determination of 3 coordinates in ELINT stations, based on measuring two distance differences and direction finding (DF) in the elevation plane, can, with a smaller number of side stations (two instead of three), provide accuracy no worse than the known TDOAM. However, this requires that the RMSE value for DF in elevation should be tenths of degrees. The practical application of HM is possible for the issuance of target designations on air defense missile systems radar.*

***Keywords:** hybrid method; bearing measurement; electronic intelligence; time difference of arrival method; comparative analysis of methods; accuracy of coordinate measurement.*

1. Introduction

1.1. Motivation

Existing ground electronic intelligence (ELINT) stations present in the armed forces of various countries, designed primarily for airspace control [1]. To determine the coordinates of radio emission sources (RES) in most existing ELINT stations, the time difference of arrival (TDOA) method is used, which is the best in terms of accuracy [2, 3]. The TDOA method (TDOAM) is implemented by simultaneous reception of signals by spatially separated receiving posts [4, 5]. Estimation of the signal delay can be performed in different ways, for example, the spectral processing method [6]. It is known [7] that for the determination of planar coordinates (2-coordinate option), it is necessary to have a central receiving station (CS) for joint signal processing and two side receiving stations (SS), which are located on the same line and remote from CS at a distance of 10..40 km. This allows the implementation of a sectoral surveillance zone with a width of about 120º. For third coordinate measurement (elevation angle, altitude) using TDOAM, it is necessary to have, except CS, at least three spaced SS [5, 8]. When placing a "star" of such a 4-position means that on the ground, in addition to determining the altitude of air targets, it is also possible to organize a circular area observation [9]. The need for a three-coordinate execution of the ELINT station becomes especially relevant in such cases, when the station is part of the air defense forces and is used as a targeting source for active radar of missile guidance from air defense missile system or active jamming station for airborne radar. These means typically use highly directional antennas in both planes.

1.2. State of the art

In TDOA system, determination of the third coordinate of an air target (altitude) can be implemented in another way, without using the TDOA measuring operation [2, 9]. To do this, it is necessary to implement a direction-finding channel in the CS for the target elevation angle [10, 11]. The solution to this problem is connected with the choice of the necessary design of the CS antenna system and a suitable direction finding (DF) method while maintaining the basic property of the TDOA station (high precision of plane coordinates). At the same time, the need for a third SS disappears and the three-position station becomes a three-coordinate. Reducing the number of SS is a positive effect of such construction. The option of joint use of TDOA and DF was studied back in the 70s of the last century in Military Engineering Radio Engineering Academy of Air Defense (Kharkiv city) for use in passive radar for airborne active jammers [2] and had at that time the name "elevation-time difference of arrival of passive radar". Recently, there has been renewed interest in the joint use of angle of arrival estimation (AOA) and TDOA methods in radio monitoring systems and ground ELINT means [12, 13]. The combination of two different methods for determining coordinates in one passive supervision station was called the hybrid method (HM) [14, 15]. In this article, we will also use this method, meaning in this name the combinations of “TDOA + DF in the elevation plane”.

An example of the application of such an HM is the three-position ELINT station DWL002 and its early analogue YLC-20 [12], which was designed and manufactured in China. The appearance of the receiving station DWL002 is shown in Fig. 1.

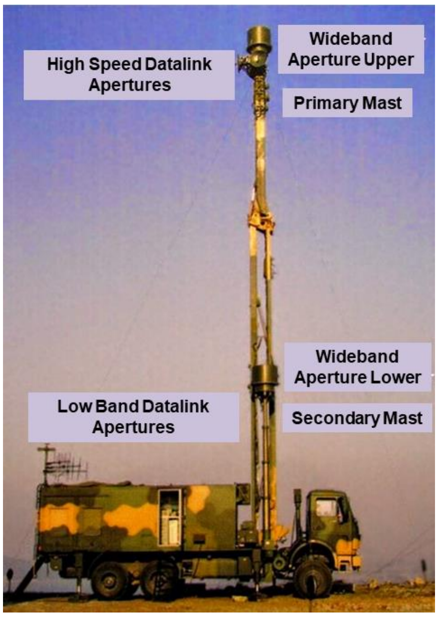

Fig. 1. Ground ELINT station DWL002 (China)

The message [12] states that this station is used as a target designation source for radar of air defense missile systems. As shown in Fig. 1, a distinctive feature of the station is the presence of two identical antenna systems, which are located on two masts and spaced in the vertical plane by several meters, which implies their use for DF in elevation. The DF method is not specified in the message, but it can be assumed that using the amplitude-phase method with the need to eliminate the ambiguity of phase measurements. Let's pay attention to the fact that due to the second antenna system, a the three-coordinate version is implemented without a third CS.

1.3. Objective and approach

A legitimate question arises: what are the indicators of the accuracy of determining the coordinates in a comparative relation of the two discussed methods (TDOA and hybrid)? Comparative analysis will also make it possible to evaluate the requirements for DF accuracy in the elevation plane, where the accuracy of coordinate information in TDOAM and HM is approximately the same. In this formulation, the problem of comparative analysis of the two methods was not considered in well-known publications. This article is devoted to solving these issues.

The goal is to conduct a comparative analysis of two options for the composition ground ELINT stations in terms of accuracy (measurement) of determining coordinates. The options differ in the amount of receiving stations and the type of primary parameters measured.

2. Methods

Let’s consider a station in which the positions of CS and SS match Fig. 2. CS («0») is located at the origin of the Cartesian coordinate system. Described location of CS and SS sometimes called «T-shaped» [15] and is usually used for surveillance in the sector $\pm 60^{\circ}$. Distances between CS and SS 1, 2, 3 denoted as L_1, L_2, L_3. We assume that the stations are located on a flat surface and have coordinates: $CS - x_0 = 0,\ y_0 = 0,\ SS - x_k,\ y_k (k = 1...3)$.

The heights of the CS and SS antennas do not play a significant role in solving the problem under consideration. We assume that they provide joint reception of signals in the analyzed ranges. Radio emission source at the point x_i, y_i, z_i. Its altitude $h = z_i$ is such that it provides electromagnetic availability of the signal by all stations. Using TDOAM the primary parameters are three distance differences to RES $\Delta r_k = D_0 - D_k (k = 1...3)$. Where D_0, D_k – downranges

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up to RES from CS and SS. In the case of HM, the system is excluded from SS3 (shown by dotted line). In this case, the CS includes a device for measuring the elevation angle of RES ε_i and primary parameters include the following measured quantities $\Delta r_1, \Delta r_2, \varepsilon_i$.

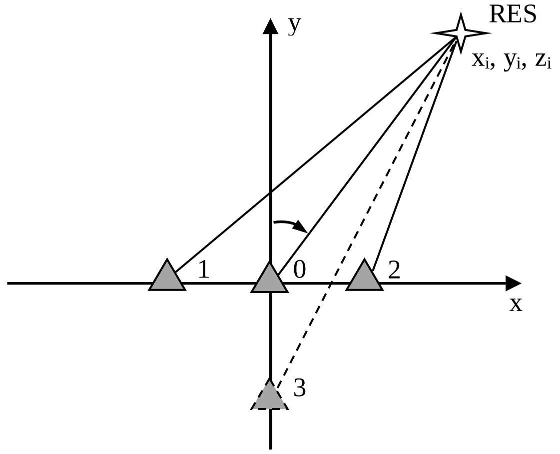

Fig. 2. Location of CS and SS on the ground

A comparison of TDOAM and HM will be carried out using Root Mean Square Error (RMSE) determination of planar coordinates and altitude of RES. Accuracy will be estimated in a known way [16, 17], based on linearization of functional dependence between measured primary parameters (range difference $\Delta r(x,y,z)$, angle of elevation $\varepsilon(x,y,z)$ and spatial coordinates by way of Taylor expansion with deduction of the first two terms of series [18]. Here, the accuracy of measuring the primary parameters and their derivatives with respect to coordinates plays a significant role x, y, z obtained at a point x_i, y_i, z_i We will assume that the measurement errors of parameters Δr_k not correlated with each other and RMSE equal $\sigma_{\Delta r}$, and RMSE of the DF in elevation will be denoted σ_ε.

In accordance with Fig. 1, the functional connection of primary parameters with coordinates x, y, z presented as

$$\begin{aligned}\Delta r_k(x,y,z) = D_0 - D_k = \sqrt{x^2+y^2+z^2} - \\ -\sqrt{(x_k-x)^2+(y_k-y)^2+z^2}\end{aligned};$$

$$\varepsilon(x,y,z) = \operatorname{arctg}\left(\frac{z}{\sqrt{x^2+y^2}}\right); \ (k=1...3), \qquad (1)$$

The results of the calculations are the linear RMSE of the planar coordinates $\sigma_p = (\sigma_{x^2} + \sigma_{y^2})^{1/2}$ and RMSE of altitude σ_z.

3. Results

Calculations have shown that the presence of SS3 has very little effect on the accuracy of determining planar coordinates σ_p and both considered methods give almost the same result. There are insignificant differences only at short ranges to the radio source. Significant differences appear only in the results of the evaluation of radio source altitude σ_h.

As an illustration, in Fig. 3 shows the results of calculating the indicator σ_h depending on the horizontal distance $D_{0,l}$ for two methods. The initial data are given in the caption. It can be seen from the figure that the RMSE of the altitude for the HM has an approximately linear relationship with $D_{0,l}$ and for the TDOAM it has a quadratic relationship. Starting from a certain range $D^*_{0,l}$ when using the GM, the height is determined more precisely.

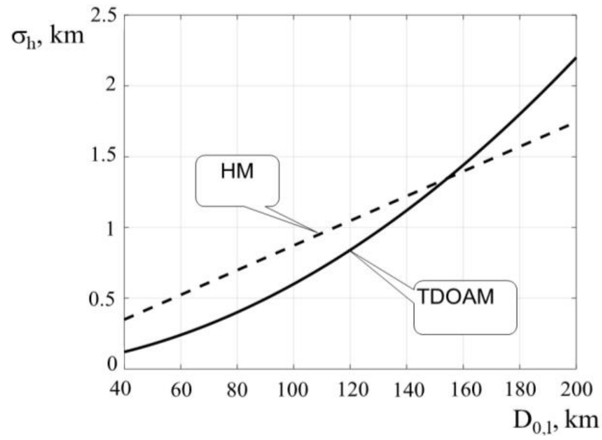

Fig. 3. Dependence of the RMSE altitude on the horizontal range

$(\sigma_{\Delta r} = 5\text{ m}, \sigma_\varepsilon = 0.5^\circ, \ h = 5\text{ km}, L_3 = 20\text{ km})$

To be able to compare two methods in terms of the accuracy of determining the altitude h for any initial data, we will find analytical relationships for the RMSE σ_h, considering only two stations – CS and SS3, since only they participate in determining the 3rd coordinate. The comparison will be performed in a situation where the radio source is on the axis y $(x_i = 0, y_i = D_{0,l}, z_i = h)$. Note that the system configuration chosen for the study and the placement of the radiation source on the y axis for analysis of the TDOA method correspond to the maximum accuracy of the TDOA method.

Under these conditions, the altitude h is determined by the TDOAM with the greatest accuracy. Let us explicitly find the relationship between the RMSE of the altitude estimation σ_h and the RMSE of the range difference Δr_3 for the TDOAM using the dependence $\Delta r_3(z)$ and the rule from the work [19].

From (1) for k=3 we have

$$\sigma_h^{(rd)} = \frac{\sigma_{\Delta r}}{\left|\partial \Delta r_3 / \partial z\right|} = \frac{\sigma_{\Delta r}(D_{0,l}+h)(D_l+L_3+h)}{h\left|\Delta r_3\right|}. \quad (2)$$

Similarly, for the HM we obtain

$$\sigma_h^{(p)} = \frac{\sigma_\varepsilon}{\left|\partial \varepsilon / \partial z\right|} = \frac{\sigma_\varepsilon (D_{0,l}^2 + h^2)}{D_{0,l}}. \quad (3)$$

Here derivatives are taken at the point $z = h$.

Of greatest interest is the case of long ranges $D_{0,l}$, since target designation for air defense missile systems radars must be formed at the maximum possible range. In this case, it is possible to consider, that $D_{0,l} \gg h$; $D_{0,l} \gg L_3$; $\Delta r_3 \approx L_3$ and expressions (1), (2) can be represented in approximate form

$$\sigma_h^{(rd)} \approx \frac{\sigma_{\Delta r} D_{0,l}^2}{hL_3};$$

$$\sigma_h^{(p)} \approx \sigma_\varepsilon D_{0,l}. \quad (4)$$

From here we obtain the condition, under which the accuracy of determining the height for the HM is not worse than that for TDOAM,

$$\sigma_\varepsilon \le \frac{\sigma_{\Delta r} D_{0,l}}{hL_3}. \quad (5)$$

To compare the two methods, it is also possible to indicate the range at which RMSE of altitude is the same. For $\sigma_h^{(rd)} = \sigma_h^{(p)}$ from (4) we have

$$D_{0,l}^* \approx \frac{\sigma_\varepsilon h L_3}{\sigma_{\Delta r}}. \quad (6)$$

If, as an example, we substitute in (6) the values of the quantities indicated in the caption of Fig. 3, then we get $D^*_{0,l}$=175 km. From a comparison with the data in Fig. 3 we see, that the relative differences between the approximate ratios and the exact ones are about 11%. For the condition $D_{0,l} \rangle D^*_{0,l}$ RMSE for HM is always less than that for TDOAM.

4. Discussion

Peculiarities of using the hybrid method

The main advantage of the HM over the TDOAM is the reduction in the number of SS to 2 instead of 3. This expands the possibilities of choosing a suitable location for the CS and SS on the ground, satisfying several conditions. Such conditions include the need for direct visibility between the antennas of the CS and all SS, the availability of access roads and power supplies, considerations of the necessary mutual position of the CS and SS (for example, "in line"), and remoteness from powerful ground-based RES, etc. This advantage becomes practically useful if it is possible to implement sufficiently accurate target designation in terms of both angular coordinates and distance. In modern ELINT stations, the RMSE in range is units of km (at large distances from the station), which can be considered acceptable for assessing the level of danger to air targets. The accuracy of determining the azimuth when estimating planar coordinates using the TDOAM is much higher than that in active radars. For example, in the Vera-NG station, the errors in determining the azimuth correspond to the value 0.01º [7]. Such target designation accuracy becomes even redundant compared with the required accuracy. Direction-finding accuracy in elevation (RMSE σ_ε) must correspond to the requirements for target designation accuracy of the means, that is the direct consumer of information (air defense missile system radar or jamming station). The best situation is when the errors of target designation in elevation angle with a high probability do not go beyond the width of the angular pattern of the radar (jammer station). This ensures the capture of the target for auto-tracking "with a shot" (without searching).

The issues of choosing a DF method in terms of elevation and its technical implementation, which considering the peculiarities of using the combination of TDOAM + DF, play a key role in the use of HM. Let us note these features are available in almost all types of known ELINT stations. These features include the coordinated non-search nature of the survey of space when implementing time difference of arrival measurements through the use of weakly directional (therefore, small-sized) antennas in the horizontal plane, providing instantaneous reception of signals in the sector ±60º. So, for example, in the station Vera-NG the size of the antenna system is limited by the size of the cylindrical module 0,5x1,8 m, therefore, DF in elevation should also be based on the non-search principle [10]. The observation sector in the vertical plane can be limited to the range $\varepsilon \approx 0...30^\circ$, how it is done in the stations of the Czech company “ERA” (“Tamara”, “Vera-E”, “Vera-NG”). The frequency range of DF measurements

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can be limited to those values that are most commonly used on board airborne targets. This includes the frequency section of waves near 1 GHz, where response signals of the "friend or foe" identification systems, interrogation signals of the TACAN-type short-range radio navigation system and signals of the Link-16 data transmission system can be emitted. Be sure to also use the 8...12 GHz frequency section for DF, where the airborne radars of aircraft and helicopters operate. At these frequencies, in addition to obtaining coordinate information, it is possible to determine the type of aircraft by the characteristic features of radar signals.

When implementing elevation DF, the use of the amplitude-phase method can be considered as a preliminary option. To achieve this, it is necessary to have two identical antenna systems with a vertical separation of the phase centers by d, similar to how it was done in station DWL002 (see Fig. 1). In each antenna, identical radiation patterns with mismatched maxima in the vertical plane are formed, which are the basis of the monopulse amplitude DF and allow a rough estimate of the angle ε. Refinement of the coordinate ε is carried out using the phase method by measuring the phase difference of the signals at the outputs of two antennas

$$\Delta\varphi = \frac{2\pi d}{\lambda}\sin(\varepsilon), \tag{7}$$

here λ is the wavelength. To eliminate anomalous errors caused by the ambiguity of measurements of the phase difference $\Delta\varphi$, it is necessary that the amplitude DF errors with a high probability do not exceed the unambiguity of phase measurements [10]. Such a two-scale method for estimating the angle ε can provide high accuracy. A separate detailed study of this method is required. In this case, it is necessary to consider the influence of reflections from the Earth and local objects on the accuracy of DF [20]. The greatest influence is expected in the frequency range around 1 GHz, where the reflections are close to the specular type. It can be assumed that the reduction of this influence can be achieved using the results of cross-correlation of signals received by the CS and SS for phase measurements.

Conclusions

The hybrid method of high-precision determination of 3 coordinates in ELINT stations, based on measuring two distance differences and DF in the elevation plane, can, with a smaller number of side stations, provide no worse accuracy than pure TDOAM. However, this requires a fairly accurate DF. The data given in Fig. 3 and relation (5) show that the DF RMSE value should be tenths of degrees.

Future research directions. Further research should be directed towards the development of a high-precision two-scale method of elevation DF. The essence of the method is as follows: in the first stage, a rough estimate of the elevation angle ε of the RES is carried out using the amplitude-phase method, and in the second stage, the obtained value is refined by measuring the phase difference of the received signals using the phase DF method.

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Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript contains no associated data.

Use of Artificial Intelligence

The authors confirm that they did not use artificial intelligence methods while creating the presented work.

All the authors have read and agreed to the published version of this manuscript.

References

1. Smirnov, Y. A. *Electronic intelligence*. Moscow, Military publishing house, 2001. 456 p.
2. Almazov, V. B. *Methods of passive radar*. Kharkiv, VIRTA PVO Publ., 1974. 84 p.
3. Comparison of methods for determining the geographic location of a signal source based on the difference in arrival time and angle of arrival of the signal. Available at: https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-SM.2211-1-2014-PDF-R.pdf (accessed 22.07.2023).
4. Shi, J., Wang, G., & Jin, L. Moving source localization using TOA and FOA measurements with imperfect synchronization. *Signal Processing*, 2021,

vol. 186, article no. 108113. DOI: 10.1016/j.sigpro.2021.108113.

5. Sun, Y., Ho, K. C., Yang, Y., Zhang, L., & Chen, L. Computationally attractive and statistically efficient estimator for noise resilient TOA localization. *Signal Processing,* 2022, vol. 200, article no. 108663. DOI: 10.1016/j.sigpro.2022.108663.

6. Oleinik, V. A., & Lukin, V. V. Modified method for signal delay estimation using robust DFT. *Radioelectronic and computer systems*, 2017, vol. 3, pp. 4-13. DOI: 10.32620/reks.2017.3.01.

7. *VERA-NG. Sees without being seen.* Available at: https://www.era.aero/en/military-security/vera-ng (accessed 22.07.2023).

8. Yang, G., Yan, Y., Wang, H., & Shen, X. Improved robust TOA-based source localization with individual constraint of sensor location uncertainty. *Signal Processing*, 2022, vol. 196, article no. 108504. DOI: 10.1016/j.sigpro.2022.108504.

9. *A 3D Passive Surveillance System VERA Accuracy Analysis*. Available at: https://www.researchgate.net/publication/3892316_A_3D_passive_surveillance_system_VERA_accuracy_analysis (accessed 22.07.2023).

10. Kobzev, A. V., & Murzin, M. V. The method of phase direction finding of radio sources with unknown modulation using ring antenna arrays. *Applied radioelectronics*, 2015, vol. 14, no. 2, pp. 150-154.

11. Sklar, J. R. *Modern HF Signal Detection and Direction Finding*. Massachusetts Institute Technology Publ., 2018. 368 p.

12. Kopp, C. *Warsaw Pact / Russian / PLA Emitter Locating Systems / ELINT Systems. Technical Report APA-TR-2008-0503*. Available at: https://www.ausairpower.net/APA-Warpac-Rus-PLA-ESM.html (accessed 22.07.2023).

13. Liu, J., & Guo, G. Pseudolinear kalman filters for target tracking using hybrid measurements. *Signal Processing,* 2021, vol. 188, article no. 108206. DOI: 10.1016/j.sigpro.2021.108206.

14. *TDOA and AOA hybrid geolocation systems.* Available at: https://www.rohde-schwarz.com/ae/solutions/test-and-measurement/spectrum-monitoring/hybrid-geolocation-systems/tdoa-and-aoa-hybrid-geolocation-systems_250147.html (accessed 22.07.2023).

15. Nicholas, A. O'Donoughue. *Emitter Detection and Geolocation for Electronic Warfare.* Artech House Publ., 2020. 332 p.

16. Torrieri, D. J. Statistical Theory of Passive Location Systems. *IEEE Transactions on Aerospace and Electronic Systems*, 1984, vol. AES-20, no. 2, pp. 183-198. DOI: 10.1109/TAES.1984.310439.

17. Shirman, Y. D., & Manzhos, V. N. Theory and technique of processing radar information against the background of interference. Moscow, Radio and communication Publ., 1981. 416 p.

18. Chernyak, V. S. *Multi-position radar*. Moscow, Radio and communication Publ., 1993. 416 p.

19. Saibel, A.G. Fundamentals of the theory of accuracy of radio engineering methods of location. Moscow, State edition Publ., 1958. 53 p.

20. Anikin, A. S., & Denisov, V. P. Errors in location of radio-frequency sources by mini-antennas in the surface reflection. *TUSUR reports*, 2012, vol. 1, no. 2 (26), pp 11-19.

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ПОРІВНЯННЯ ДВОХ ВАРІАНТІВ ПОБУДОВИ ТРИКООРДИНАТНИХ СТАНЦІЙ РАДІОТЕХНІЧНОЇ РОЗВІДКИ

Анатолій Кобзєв, Михайло Мурзін,
Ілля Грідасов

Предмет статті – методи вимірювання координат у наземних засобах радіотехнічної розвідки (РТР). **Мета** – проведення порівняльного аналізу двох варіантів побудови наземних засобів повітряної РТР за показниками точності вимірювання координат. **Завдання:** проведення оцінки показників точності визначення координат різницево-дальномірного (РДМ) та гібридного методів (ГМ); отримання аналітичних співвідношень оцінки середньоквадратичної похибки (СКП) точності вимірювання висоти джерел випромінювання зазначених методів; на основі отриманих оцінок та аналітичних співвідношень проведення порівняльного аналізу методів, зокрема умов, за яких точність координатної інформації, отриманої обома методами, можна порівняти; розробка рекомендацій щодо практичного застосування гібридного методу виміру координат. Використовуваними є **методи** теорії вимірювань та теорії оцінки координатної інформації. Отримані наступні **результати.** Проведено порівняльний аналіз РДМ та ГМ по СКП визначення площинних координат та висоти джерела радіовипромінювання (ДРВ). Оцінка точності проводилася відомим способом, заснованим на лінеаризації функціональної залежності між вимірюваними первинними параметрами (різниці дальностей, кута місця) та просторовими координатами шляхом розкладання в ряд Тейлора з утриманням перших двох членів ряду. Обчислення показали, що наявність третьої бічної станції дуже мало впливає на точність визначення площинних координат. Значні відмінності з'являються лише при оцінюванні СКП висоти ДРВ. З метою порівняння методів отримано аналітичні співвідношення для оцінки СКП вимірювання висоти. Визначено умову, за якої точність визначення висоти для ГМ не гірша, ніж для РДМ (точності однакові). Починаючи з цього значення і далі при використанні ГМ висота визначається точніше. **Висновки.** Гібридний метод високоточного визначення 3-х координат у станціях РТР, заснований на вимірі двох різниць дальностей і пеленгації у кутомісній площині, може при меншій кількості бічних станцій (дві замість трьох), забезпечити точність не гірше, ніж відомий РДМ. Однак при цьому потрібна високоточна пеленгація по куту місця, а саме величина СКП пеленгації має становити десяті частки градусу. Практичне застосування ГМ можливе для видачі вказівки на радіолокаційні станції ЗРК.

Ключові слова: гібридний метод; вимірювання пеленгу; радіотехнічна розвідка; різніцеводалекомірний метод; порівняльний аналіз методів; точність вимірювання координат.

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