ISSN 2347 - 3983
Volume 8. No. 5, May 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter78852020.pdf
https://doi.org/10.30534/ijeter/2020/78852020

The Method of ADS-B Receiver Systems Synchronization using MLAT Technologies in the Course of Radar Control of Air Environment

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ABSTRACT

The article proposes the method of ADS-B receiver systems synchronization using MLAT technologies. The purpose is to develop the synchronization method of automatic dependent surveillance – broadcast ADS-B in the course of radar control using MLAT technologies. The synchronization method of ADS-B receivers in the course of radar control of air environment using MLAT technologies has been developed, which ensures the necessary timing accuracy. The proposed algorithm is implementing synchronization method of ADS-B receiver systems with the use of multilateration technologies. The scientific novelty of obtained results is as follows. It was established that the advantages of using the proposed synchronized method of ADS-B receivers are the simplicity of synchronization process, the possibility of using random air object as a control object which equipped with ADS-B transponders and located in the ADS-B receiver systems zone action. The scheme of diagnostics in the automated system of technical diagnostics for a case of complex use of energy-static, energy-dynamic and electromagnetic methods is resulted. The order of complex use of energy-static, energy-dynamic and electromagnetic methods of diagnosis is given.

Key words: ADS-B, MLAT, synchronization, air environment, dependent observation, airspace control, coordinates, GPS, the scheme of diagnostics, the automated system of technical diagnostics.

1. INTRODUCTION

Over the past decades, the intensity of air traffic has increased many times over [1–3]. At the moment in the area of responsibilities of air traffic control (ATC) units there are a large number of both civilian and military air objects (AO), which certainly make difficult to performance tasks of maintaining high-quality and effective radar control of air environment in the radar coverage area [2].

The capacity of available radar methods for implementation of radar control (RC) and release of radar information (RI) with increased requirements for the accuracy of determining the coordinates of AO are somewhat limited [4–12].

At this time the multilateration (MLAT) technologies are widely used in ATC. MLAT is based on the fact than system of several receivers (at least three) is capable of AO coordinate measuring, even when air object does not forward data to space about its location. As a MLAT receiver system ADS-B receivers are used [13–14].

It is known [15–18] that several factors are influence on the positional accuracy of air object, they are: radar performance characteristics (directional diagram width, signal-noise ratio, etc.), weather, ground relief, instrumental errors of radar (inaccuracy of antenna pointing, controller errors occurred while visual withdrawal azimuth of targets), high-quality and accurate radar synchronization.

For ADS-B data reception from AO, rather cheap and miniature radio receivers are used [13–14]. In that regard, it becomes possible to increase positional accuracy and enrichment about the air object (AO type, its call sign, etc.).

It is known [3, 13–16, 19–20] that one of the factors that influence on the AO positional accuracy is accurate time synchronization of receiver systems which provide position finding of the air object using MLAT technologies, therefore, the development of ADS-B receiver system synchronization method is relevant.

2. PROBLEM ANALYSIS

For the system element concerted efforts, various synchronization techniques of signal transmission which are divided into one-way and two-way are used [15–16]. Synchronizing signal is a radio signal which parameters that are strictly related with provisional scale of system. One-way methods synchronizing signal transmitted in the direction from chronometer signal with system time scale (elementary item) to the chronometer which provisional scale leads to the system (element binding) [15–16, 21–22]. First of all, such methods include synchronization with the help of satellite-aided tracking system. Two-way methods used not only forward direction but also opposite direction. As a result of evaluation, the differences in provisional scales according to two elements (on the base and on the link) it is possible to increase the synchronization accuracy in comparison with one-way methods. The RMS (root-mean-square) synchronization is in error by one-way synchronization approximately 1-50 ns and in two-way synchronization approximately 0,001-2 ns. The main factor affecting error of synchronization in these approaches is error in means of receiving calibration. The synchronization potential using the proposed algorithms is about 10 ns. The considered algorithm can be adapted for other spatially located systems.

Currently, almost 99% of air objects in the airspace are equipped with ADS-B transponders and operate in the air traffic control Radio Beacon System [13–14]. The ADS-B technology is in fact an element of RDS mode “S”.

Automatic Dependent Surveillance Broadcast (ADS-B) is a technology of cooperation observation in which an AO determines its location through Global Positioning System and distributes it into space. This information can be received by both ATC ground stations and other aircrafts allowing crews to be more situationally aware [2, 13–14].

ADS-B technology can operate in two modes: “ADS-B Out” and “ADS-B In” [13–14].

In the "ADS-B Out” mode the information on the air object precious location, flight level and speed as well as other data from airborne systems of AO is disseminated through airborne transmitter [13–14].

In the “ADS-B In” mode the information is received from Flight Information Services-Broadcast (FIS-B) and Traffic Information Services-Broadcast (TIS-B) channels as well as other ADS-B data such as direct communication with air objects that are in the vicinity [13–14].

In comparison with modern radar equipment, data of AO current location which defined by ADS-B system have significantly higher accuracy due to the fact that AO coordinates determined by Global Position System (GPS) on-board navigator [13–14, 19, 21].

The discretization of coordinate data transmission (2 times per second) is also significantly decrease data discretization of radar equipment. In most cases, the value of speed and course is taken from GPS on-board navigator but also can be taken from other airborne equipment. For the most parts, the altitude value is taken from barometric pressure altimeter of air object.

It should be remembered that not all even modern AO which appointed with ADS-B equipment. But now almost all air objects have ability to work in Mode “S” of secondary location RBS. In the secondary location mode, AO respond to the demand signal of surveillance radar of traffic management office. The answer is carried out at the same frequency as the ADS-B, namely 1090 MHz. Accordingly, ADS-B receiver is also capable for receiving the reply signals from air objects responding to requests from surveillance radars. And since AO nearly always operate a flight in the field of surveillance radars reply signals are almost always present. By analyzing these signals it is possible to possible to obtain the same data as from ADS-B (information about altitude, ICAO aircraft registration, SQUAWK, call sign) except for the current coordinates [2, 13–14]. To determine the AO coordinates which does not transmit its coordinates it is appropriate to use MLAT technologies [13–14]. In fact this is a known differential distance multipositional method of position finding. For its usage it is necessary to process a signal at least than three receivers which have spatial separation and precision time synchronization Precise timing (up to 50 ns) can be provided through GPS receiver.

It is known that the main factors that affect the positional accuracy of air objects are [13–14]: performance characteristics of receivers, the distance between receiver systems, the geometric construction of receiver systems using MLAT technologies, the synchronization of receivers in the system.

The quality of system with usage of MLAT technologies mainly depends on the accuracy of receivers synchronization. The wildly known internet resource “FlightRadar” [2] where signals from thousands of ADS-B receivers are processed uses MLAT technology.

The purpose of the article is the development the synchronization method of ADS-B receiver system under radar control of air environment using MLAT technologies.

3. MAIN MATERIAL

However, it should not be neglected that with synchronization accuracy of 1 μs error will be about 300 m.. Accordingly, to provide for better quality position finding of AO it is necessary to ensure synchronization accuracy of less than 1 μs.

It is known that even in reply signal, for example in IFF (Identification, friend and foe) (“Parol”, “Kremniy-2”) each pulse is more than 1 μs and is about 2-3 μs [13–14]. Therefore, when it comes to measuring time, it is necessary to determine what exactly is meant by the concept of “time”. This may be, for example a first pulse front. In addition, making an accurate chronometer at each receiving point is not a problem, this can be achieved by using crystal-controlled oscillator (CCO) [13–14]. However, there is a question of synchronizing these chronometers.

The essence of synchronization method. Consequently, there is a chronometer at each receiving point, but this chronometer is not synchronized.

ADS-B receiver system layout using MLAT technologies is shown in Figure 1.

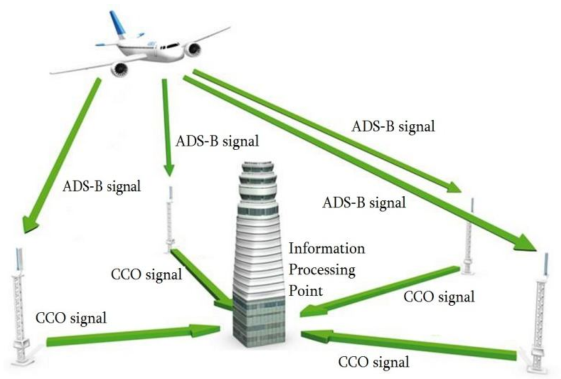

Figure 1: ADS-B receiver system layout using MLAT technologies

For each message that is received, a register value (signal reception time) is added. This data is transferred to the information processing point. The data in themselves do not carry useful information, since there is no information about the coordinates, and the chronometers at the points of reception are not synchronized. However, it should not be neglected that that at the reception points, ADS-B receivers are used as receivers, which are capable to receive signals from air objects which appointed with the corresponding ADS-B equipment at a frequency of 1090 MHz. Thus, if an AO appears in the coverage area of the receiver system that transmits its coordinates to space, it is possible to use them as reference.

Furthermore, an AO which appointed with appropriate ADS-B equipment can consciously send into the area of responsibility of radar units and use the signal from it as a reference. Knowing the exact coordinates of the AO that are transmitted from the AO according to the ADS-B system, it is possible to determine the reference difference in the time of signal arrival between individual receiving points and the difference in the values of CCO between the same receiving points. The corrected value using which it is possible to provide time synchronization between system receivers, is determined by the expression (1):

$$P = \Delta t_{ADS-B} - \Delta t_{CCO}, \quad (1)$$

where Δt_{ADS-B} – sample difference in time of arrival between individual receiving points; Δt_{CCO} is the difference value of CCO between individual receiving points.
Using MLAT technology and having corrected value P for each receiving point can be taken into account when air objects located in the system coverage area does not transmit its coordinates.

The algorithm that implements the synchronization method of the ADS-B receiver system using MLAT technologies is shown in Figure 2.

At the first stage, messages (signals) are received from an AO which appointed with ADS-B equipment.

At the second stage, the time values of the CCO are attached to each message at each receiving point and transmitted data to the information processing point.

At the third stage, using the expressions (2), (3) and (4), the time of arrival differences are calculated according to ADS-B data and expression (5) – the time of arrival differences according to crystal-controlled oscillator:

$$t_1 = \frac{D_1}{c}, \quad (2)$$

$$t_2 = \frac{D_2}{c}, \quad (3)$$

$$\Delta t_{ADS-B} = t_1 - t_2, \quad (4)$$

where D_1 is the distance from AO to first receiver; D_2 is the distance from AO to second receiver; c is the light velocity; t_1, t_2 is a time of arrival to the first and second receiver;

$$\Delta t_{CCO} = t_{1CCO} - t_{2CCO}, \quad (5)$$

where t_{1CCO} is a time of arrival to the first CCO; t_{2CCO} is a time of arrival to the second CCO.

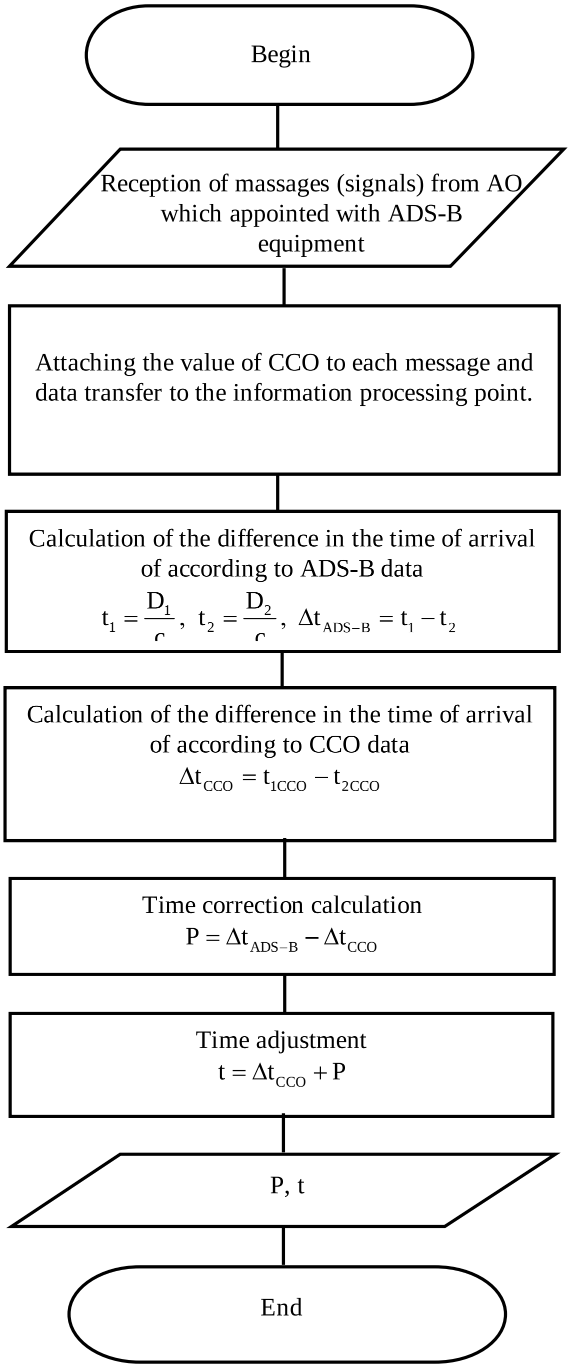

Figure 2: The algorithm that implements the synchronization method of the ADS-B receiver system using MLAT technologies

At the fourth stage, the time correction is calculated by the expression (1) At the fifth stage, knowing the exact value of the time correction for each receiving point, according to the expression (6), the ADS-B receivers are synchronized using MLAT technology:

$$t = \Delta t_{CCO} + P. \tag{6}$$

As appropriate, the synchronization can be conducted at certain intervals.

In [3] there are the suggestions for construction of an automated system for technical diagnostics of objects of radio electronic equipment on the example of radars.

In Figure 3 the scheme of diagnosis in an automated system of technical diagnostics for the case of integrated using of energy-static, energy-dynamic and electromagnetic methods is presented.

The order of complex use of energy-static, energy-dynamic and electromagnetic methods of diagnosis (the order of work):
1. Power connection.
2. Connect the body bus of the digital device to the diagnostic device.
3. Submission of test tests to the input of the digital device from the output of the generator of test sequences.
4. Determining the value of diagnostic parameters for each method.
5. The signal from the output of the intelligent diagnostic system to the input of the control unit of the switch.
6. Applying a signal from the output of the intelligent diagnostic system to the input of the diagnostic device and issuing a test sequence to the input of the digital device.
7. Obtaining diagnostic information and recording it in a computer.
8. Receipt of diagnostic information to the intelligent diagnostic system and its recording in the knowledge base.
9. Comparison of the received diagnostic information with the reference.
10. Determining the technical condition of the digital device.
11. Forecasting the technical condition.
12. Determination of residual resource.
13. Determining the time of the next inspection.

4. CONCLUSION

The main advantages of the proposed method for synchronizing the ADS-B receiver system when maintaining radar control of air environment using MLAT technology is the ability to use as control objects random AO flying in the area of responsibility of the radar units and equipped with ADS-B transponders. In addition, synchronization can be performed automatically. The adjustment can be conducted at certain intervals. Using this method can significantly increase the accuracy of synchronization, which will provide a more accurate determination of the coordinates of an AO, even if the AO is not appointed with the appropriate ADS-B equipment.

As a result, the following achievements were obtained. The factors affecting the accuracy of determining the coordinates of AO are determined. The possibility of using the automatic dependent surveillance – broadcast technology and multilateration technology to improve the accuracy of determining the coordinates of AO is established. It was estimated that for the qualitative determination of the AO coordinates, it is necessary to ensure the accuracy of receiver synchronization less than 1 μs. A method of synchronizing

ADS-B receivers when maintaining radar control of air environment using MLAT technology has been developed, which ensures the necessary synchronization accuracy. An algorithm that implements the synchronization method of the ADS-B receiver system using multilateration technology is proposed.
The scheme of diagnostics in the automated system of technical diagnostics for a case of complex use of energy-static, energy-dynamic and electromagnetic methods is resulted. The order of complex use of energy-static, energy-dynamic and electromagnetic methods of diagnosis is given.

The direction of further research is the practical application of the developed method for synchronizing the ADS-B receiver system using multilateration technology.

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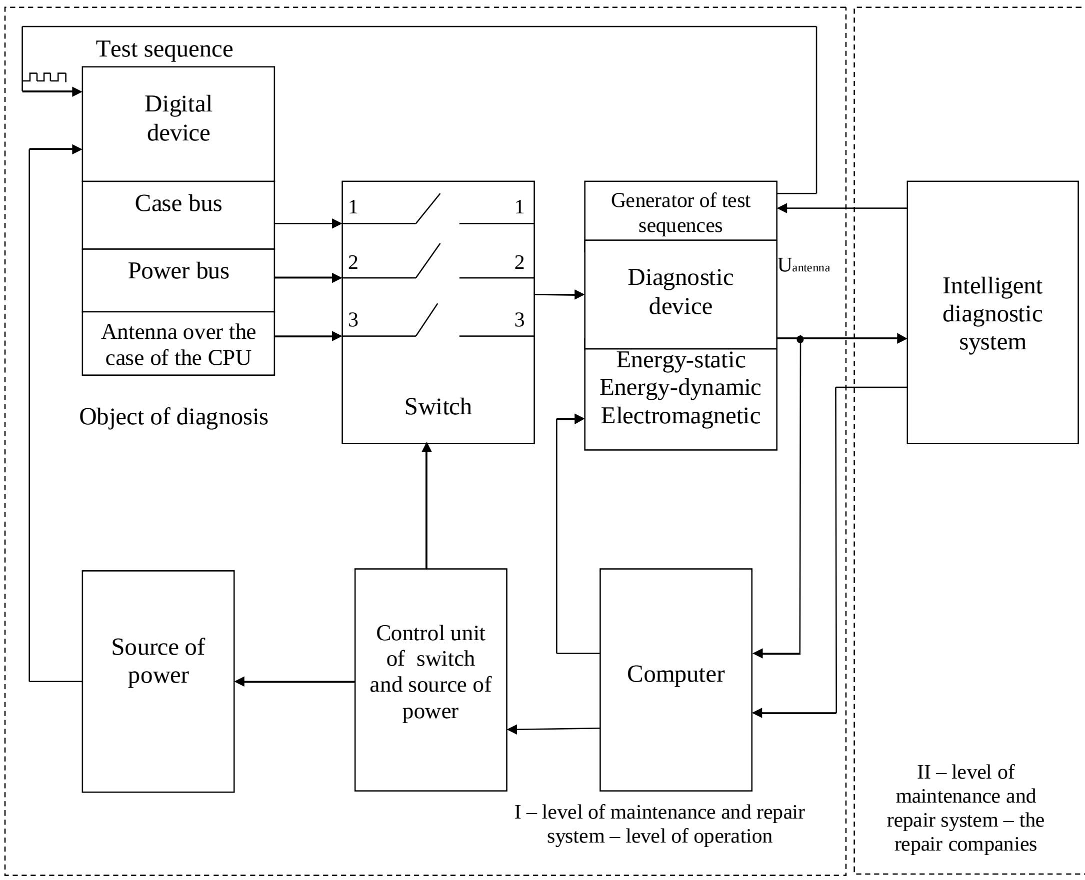

Figure 3: The diagnostic scheme in the proposed automated system of technical diagnostics for the case of complex using of energy-static, energy-dynamic and electromagnetic methods

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