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PRINCIPLES OF CONSTRUCTION OF THE NAVIGATION-LANDING SYSTEM FOR AIRCRAFT OF LOCAL AIRLINES

Kondrashov Ya. V., Fialkina T. S., Ryabets A. P.

National aviation unevercity

int2080@ukr.net

The variants of construction and use of surface and side radio equipment are considered in the article, the indexes of quality of the system are certain, priorities are placed for its different modifications.

В статье рассмотрены варианты построения и использования наземного и бортового радиооборудования системы, расставлены приоритеты для различных ее модификаций.

Introduction

In the article [1] is noted a functional and hardware-software flexibility based on signal make technologies DME (Distance Measuring Equipment), mobile multiposition radio range navigation-landing air system (hereinafter MPSP), which consists in the fact that different problems during flying aircraft of local airlines can be solved by changing the software on-board computing device. The hardware is part of both airborne and ground equipment, can remain practically unchanged.

Board equipment MPSP conditionally consists of two parts — a staff radio-range station DME/P [2] and the newly introduced parts (control, display, communicate with other on-board systems), depending on the type of aircraft.

Ground equipment also includes options for its construction and use.

Competent core design trend should be a simple as possible (minimal possible cost) while maintaining the format of DME signals (in terms of carrier frequency and duration of response radio pulse), the implementation of an acceptable accuracy range measurement system.

Independent transponder beacons application case

Based on the fact that the on-board unit DME/P is standard equipment, navigation-landing system (MPSP) for aircraft of local airlines can be built as follows (Fig. 1).

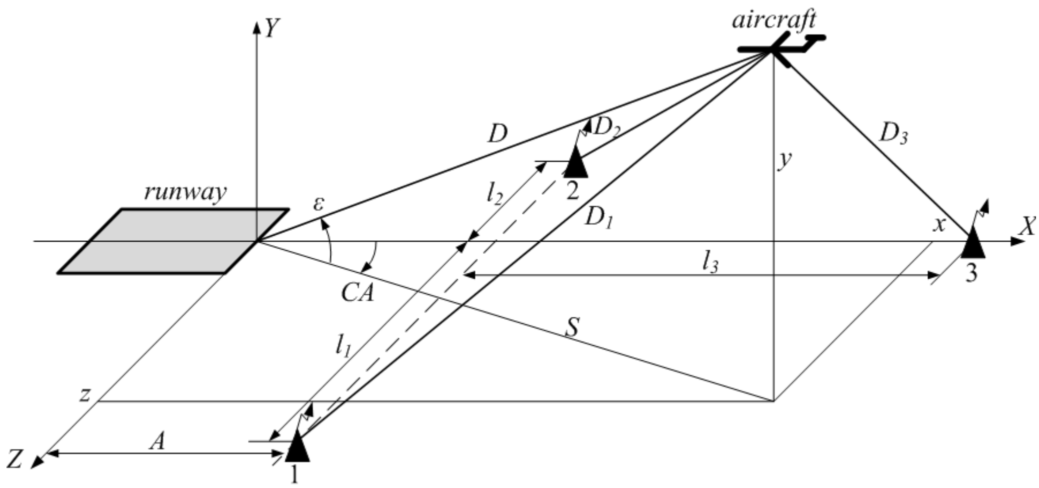

Fig. 1. The placement of beacons and geometric ratio under aircraft flight

Each of the three (1, 2, 3) or four transponder beacons, placed in the area of the runway, respond to the request block airborne DME/P at its fixed-frequency coded channel (FFCC) in accordance with FFCC table DME system. In this case, the onboard unit DME/P operates in its normal mode directional scanning (in foreign literature — the mode of "multi DME") and consistently on the cycle is set to work with each transponder beacon. It is envisaged that during the 5sec on-board unit can request up to five transponder beacons, regardless of FFCC placement. Capturing beacons, ie work of airborne unit DME/P on the signals RPI, can be performed on any transponder beacon because they are completely equivalent to the signals RPI radiation, but everyone on its carrier frequency and with its code-interval between the pulses of the pair (with the option of temporary coding).

Accuracy of slant range measuring for each beacon will be the same and is determined by the resultant precision of navigation-landing systems. It is literal, because each beacon is working without adjustment of the carrier frequency and code range on request and on the response.

The advantage of this variant of constructing navigation-landing system is the identity of the transponder beacon and the absence of any need whatsoever improvement board DME/P unit [2].

However, in the variant of independent FFCC there are significant shortcomings. They lie in the fact that the information on the aircraft board of its location is calculated by the three (four) ranges coming not at the same time, and this is the source of dynamic errors. For example, during the adjustment to a different beacon and the other measuring distance, equal to, for example about 0,5sec aircraft flied of meters, therefore, for the coming time of four distances (~ 2 sec) location of aircraft cannot be considered as unchanged. This leads to the necessity of introducing of the extrapolation algorithm of each of the ranges at the time of last range measurement, which complicates the implementation of the software for on-board computing device and does not fully eliminate the dynamic error of aircraft location.

Retransmitter application case

Progress achieved in improving the range-finders, usage of innovation circuitry engineering, wide implementation of information microprocessing, have substantially improved the accuracy of the range measurement. This led in recent years to extensive development of aircraft positioning systems based on the DME, the so-called DPS systems (DME-based positioning system) [3].

These systems contain an aircraft scanning DME range-finder produces range measurement to different retransmitters. The values of measured distance D1, D2, … are inputted into the on-board computing device, in which the coordinates of the known DME retransmitter and distances to them are calculated the coordinates of the aircraft. DPS, using scanning DME range-finders have limitation, consisting in that the range measurement to the retransmitter is performed sequentially at intervals in which the range-finder is switch over on a new channel and produces capture of a synchronal response signal. This leads to the range measurement at different times of aircraft flight, corresponding to its different locations. To bind all the measurements to a single point of time in computational algorithm it is necessary input data of the aircraft velocity vector, its altitude, retransmitters altitude. All this leads to a decreasing of performance and appearance of additional dynamic error of aircraft positioning.

Increasing of the range measurement speed is associated with a corresponding increase of each measurement error. The accuracy of location may be enhanced by the redundancy of information about range by using of larger number of retransmitters. However, ultimately, increasing the number of used retransmitters increases the time watching of the whole "list" of them, ie also leads to a decreasing of accuracyin some moment of time. In addition, systems using a scanning DME range-finder, are required to work on a large number of frequency channels of DME-coding, which reduces the capacity of the DME system.

Also the disadvantage of DPS systems with a scanning range-finder is impossibility of usage of appeared high-precision range-finders DME/P, which allow to realize the range measurement accuracy order of magnitude higher than the previous generation of rangefinders. Range-finders DME/P with α-β filters in their measuring systems are fundamentally unable to operate in a mode of rapid range measurement and precise measurement of distance requires significantly more time consuming to work with each transponder, which can also lead to decreasing of positioning aircraft accuracy.

Furthermore, as is known, in the DME/P (landing mode) has two sub-operation: primary (IA) and final (FA) approach. Features of these sub-modes are described in Chapter 3.5 of Annex 10 of the Convention ICAO. They correspond to the following accuracy of DME/P subsystem (Standard I):

- from ± 250 to ± 85 m at the range from 37 to 9,3 km from the reference point (runway end) in sub-mode IA;
- from ± 85 to ± 30 m at the ranges from 9.3 to 0 km from the reference point in the sub-mode FA.

The transition from IA to the sub-mode FA occurs at a distance of about 13 km from the beacon DME/P.

The operation peculiarity of the requester DME/P is a mandatory transition to the FA sub-mode through sub-mode IA (including those with a random loss of signal in the FA area), as stated in IB p.7.3.5 of the Annex C to Part I of Complement 10 ICAO. This peculiarity strongly affects to the ability of usage standard transponder beacon DME/P for the construction of the landing system based on the principle of measuring of several distances on board to determine the location of the aircraft in space and the construction of the trajectory. For example, when polling (scanning) of the three beacons DME/P, given that the total time of search, IA capture, transition to FA and starting tracking at about 2sec, the difference in distance at a straight aircraft trajectory between 1-st and 3-rd range count at great distances will be:

$$\Delta D = 2t_1 \cdot V_{av} \cong 400\ m,$$

where t_1 — the total time of entering the tracking mode FA, t_1 = 2 sec; V_{av} — average speed of Sun for the period of measurement

$$V_{av} \cong 100\ m/\sec .$$

Obviously, the calculation correction of aircraft location with a glance speed is inevitable, and with a straight trajectories does not create difficulties, while the curved trajectories dramatically complicates calculation process, because it requires the introduction of data not only the aircraft speed, but the angular velocity, and also, apparently, altitude.

MPSP system is also based on the DPS principle, but it should hold with only one frequency DME channel at a temporary transponder beacon identification or three channels — at the frequency identification [1]. Ground system equipment uses only one "leading" DME transponder, which interact with two circuit and constructively simpler and therefore cheaper, significantly smaller and lighter, transponder-retransmitter. Almost simultaneous measurement of distance to all of the three transponders allows usage of high-precision range-finder DME/P as an on-board equipment and increases the accuracy of aircraft positioning determination. MPSP system works as follows (Fig. 2).

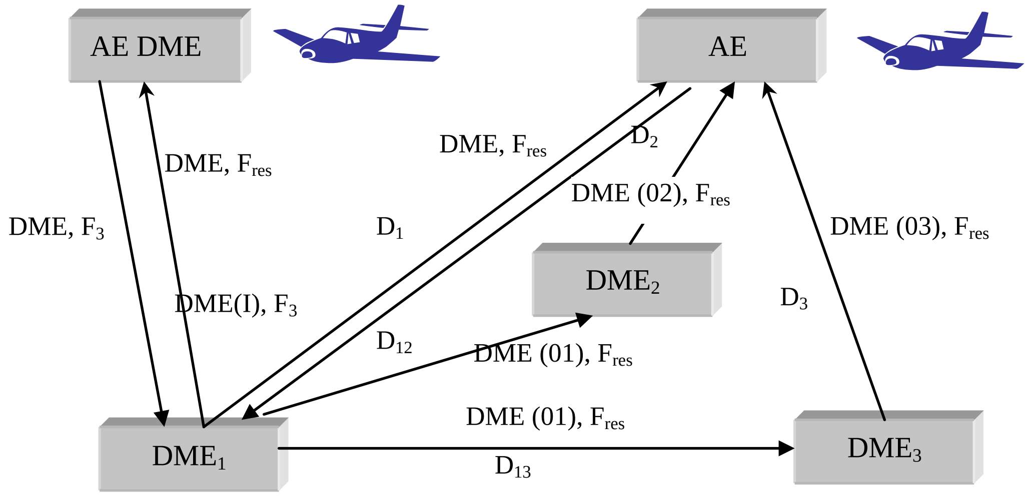

Fig. 2. Block diagram MPSP

Thereby, at one challenging signal DME (I), the AE takes the responses from all system' transponders. AE measures the radio signal transmission time of distances – $2D_1$, $D_1 + D_2 + D_{12}$ and $D_1 + D_3 + D_{13}$, and calculates ranges D_1, D_2, D_3, using constant values D_{12} and D_{13}. A computing device (CD) of onboard equipment system determines the aircraft locating using slant distances to three points with known coordinates. In a system as a transponder DME1 (lead) can be used either specially engineered transponders, designed to receive only the challenging signals DME(I) or a standard transponder DME updated to receive challenging signal DME(I) and transceiver response DME(01). According to expert assessment, the amount of corresponding improvements is ~10 ÷ 20 chips. If the standard transponder is used, the system retains ability to service aircraft, equipped by standard rangefinders DME (AE DME in fig. 2). Block diagram of the first (leading) transponder system MPSP is presented in fig. 3.

Challenging signal AE, received by the antenna A, through antenna switch AS (circulator) comes at the receiver input RCV tuned to the frequency of F3. Decoding of the standard challenging signal DME is realized by decoder D1, and decoding of identified challenging signal DME (I) — by decoder D2. During receiving challenging signal DME(I), two reply pulse pairs are coding with different delays t_0 and t'_0. Two pulse pairs come from scrambler S1 to the transmitter input TRM with a standard response code DME, and from scrambler S2 — with code DME(01). Both pairs sequentially are emitted by TRM on the response signal frequency Fres.

Block diagram of the second / third transponder (retransmitters) is shown in fig. 4.

Received by RCV signal on frequency Fres DME(01) is decoded by decoder D and then encoded with delay toh, respectively, in the second transponder as DME(02), and the third — as DME(03).

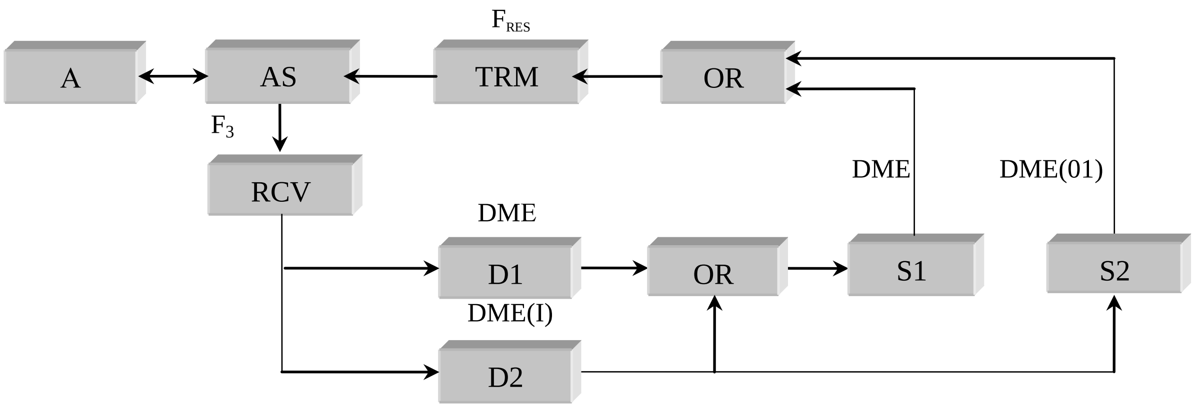

Fig. 3. Block diagram of leading transponder DME1

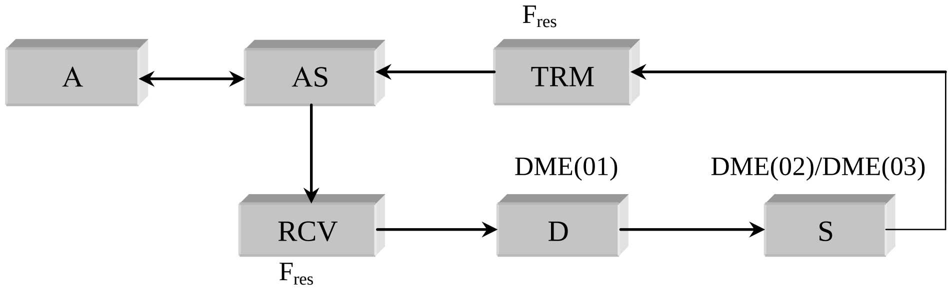

Fig. 4. Block diagram of transponders-retransmitters DME_2/DME_3

Requirement to selectivity of RCV of standard transponder DME1 stated in subsection 3.5.10 of annex convention ICAO, may be formulated much softer when specially designed transponder DME1 is used. This is due to more lenient requirements for the geographical separation of channels frequencies of MPSP system, in comparison with a system of VOR DME (VOR TAC), as also more distant diversity of fixed frequencies of system ≥ 3 MHz.

RCV of transponders DME2 (DME3) is a highly simplified modification of RCV of transponder DME1. These RCVs are designed for receiving of signal with significant magnitude, because the distances D12 and D13 are small. Input signal level RCV, equal to - 80 dB W, with bandwidth of RCV ΔF = 4 MHz, and sufficiently easy for implementation noise factor N = 20 dB provides a signal-to-noise ratio at the output of RCV more than 50 dB. In view of practical constancy of the input signal there is no necessity in usage of complicated AGC system in RCV (or any other of its implementations, provides high dynamic range and lower recovery time required for the transponder DME1 RCV).

With simultaneous injection to the range measuring unit (RMU) of system requester AE it is possible the organization of simultaneous measurement of all three ranges. In this case, the time of radiation of request signal would be the counting starting time for the three RMU reading device, and time of coming of response signals — counting stopping time. The getting values of ranges may be further with signs of transponders introduced into the AE computing unit (CU). A simpler organization of range measuring with single reading device may be organized on the basis of the standard rangefinder DME, for example, range-finder DME/P and widely known schemes ranging with pre-installing presumptive value of range in the AE computing unit CU, produced on the basis on previously obtained results.

Block diagram of such a requester is shown in fig. 5. Response signals DME, DME(02) and DME(03) are received by antenna A and through antenna switch AS (circulator) come at the RCV input, tuned to the frequency Fres. From the RCV output response signals come to three decoders D1, D2, D3. The outputs of all three decoders are connected to the RMU through the commutator C, which is controlled by RMU on readiness of the i-th range measurement. Coding of request signals DME(I) is performed by scrambler S. According to expert evaluation, the necessary amount of improvement of rangefinder DME/P, which provides implementation of additional functions of MPSP is (without improvements program) 5 ... 7 chips.

Before each measurement, RMU reading device of requester sets in the position of initial delay t_{ni} corresponding to I number of transponder. Values t_{ni} are:

$$tn_1 = t_0 + t_{y1},\ tn2 = t_{02} + ty_2,\ tn_3 = t_{03} + ty_3,$$

where $t_{02} = t_0' + t_{ou} + \frac{D_{12}}{C}$, $t_{03} = t_0' + t_{ou} + \frac{D_{13}}{C}$,

$ty1$($ty2$, $ty3$) — delays, providing a preliminary set of presumptive value of range D1 (D1 + D2, D1 + D3).

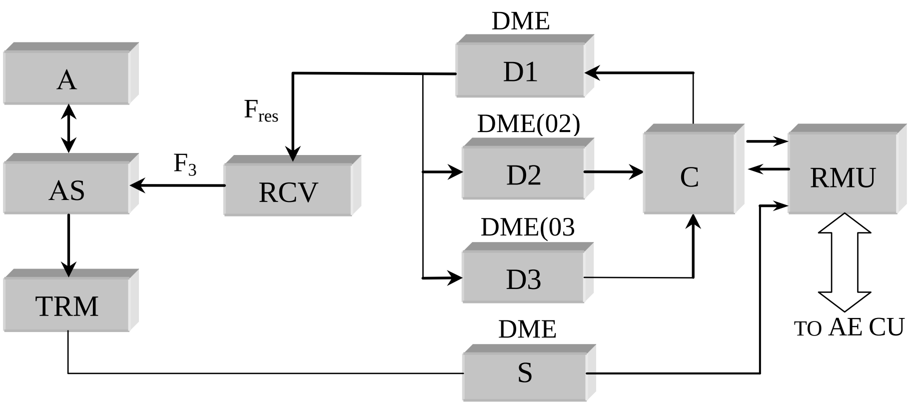

Fig. 5. Block diagram of AE requester

Thus, when using of transponder DME1, measured (except for value of initial delay t_0) time t_1 will correspond to value $2D1 / C – t_{y1}$, and when using of another transponder DME2 and DME3, t_2 and t_3 will correspond to (excluding t_{02}, t_{03}) values $(D1 + D2) / C – t_{y2}$ and $(D1 + D2) / C – t_{y3}$. Found from the system value of ranges $D1$, $D2$ and $D3$, together with the known values of the coordinates of transponders X_i, Z_i are used in the AE CU to determine the location of the aircraft.

Direction-finder of DME signals application case

There is a set of operating limitations, with which it is difficult or impossible to place the responder beacons with the required foundation. These limitations include landing sites in the mountains, on drilling offshore platforms, etc. In this case, navigation-landing system is necessary, which is placed only near the landing site, where the foundation of beacons is reduced to zero.

This opportunity can provide navigation-landing system with a direction-finder of DME signals. It includes: direction-finder DME signals (for ex. [4]), ground responder beacon DME [1], equipment for conjugation direction-finder with a responder beacon, as also onboard equipment, consisting of a block of DME/P [2], equipment for processing and indicating of azimuthal information.

Here we note that the shortcomings of this version of the system in relation to problems Sun IAL should include relatively high complexity (and comparative cost) of ground equipment.

Conclusions

The structure of building ground equipment MPSP may serve the following options:

- independent transponder beacon application case;
- retransmitters application case;
- direction-finder of DME signals application case.

The most economical, simple in construction and easy to use option is retransmitters application case.

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