Microwave Autonomous Angular Position Finding System for Middle Range Unmanned Aerial Vehicle

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Abstract – **Development and realization of autonomous microwave angular position finding system of unmanned aerial vehicle (UAV) in one (azimuthal) plane relative to ground control station (GCS) is described in this paper. Functioning of the system is based on microcontroller supported microwave monopulse receiver of original construction and is field proven.**

Keywords – **microwave link, monopulse receiver, UAV (unmanned aerial vehicle), autonomous angular position finding**

I. Introduction

System for remote guidance of unmanned aerial vehicle has great importance for its successful and safe flight, as well as fulfilling missions objective, because it has to guarantee integrity of UAV and operatorss complete control of it during the whole flight [1]. To obtain that task, it is necessary to have good quality of communication in both directions: from GCS to UAV (commands) and vice versa (telemetry and mission equipment data). One of the basic data needed by operator to make proper decisions during the UAVs mission is knowing reliably UAVs position, ie its real trajectory, so he can compare its actual to wanted position or to deliver command towards UAV to get to certain position. One and only exception from request of having good communication is when UAVs mission in some zones is under cover and in some parts of trajectory radio silence is a must. Usually, in such cases UAV performs preprogrammed trajectory and activity. Even in those cases in come back phase of flight: approaching GCS, preparing for landing and landing, communication between UAV and GCS is reestablished with finding its exact position as one of the most important data for safe landing as the most critical phase of flight.

II. UAVs Position Finding Systems

There are global position finding methods of UAV, all of them based on network of transmitters covering complete Earth, and autonomous methods - local and independent from anything outside of UAV-GCS system. Common to both methods is their aim: to define position of an object (in this case UAV) in space as precisely, quickly, reliably and cost effectively as possible. For that task three coordinates that describe UAVs position have to be found, independently of chosen reference system.

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Basically there are two kinds of global systems: the first one consisting of transmitters at Earths satellite network such as GPS as representative of space based and the second like OMEGA and LORAN-C as representatives of older, Earth surface based global systems. In global systems usually latitude, longitude and height above sea level is defined as a result of activity.

As opposite approach, functioning of autonomous RPV position finding systems do not depend of any equipment outside RPV-GCS complex itself. Of course, its quality and operation range are limited by characteristics of the chosen method of position finding (inertial-gyroscope, primary or secondary radar, Doppler radar, compass, terrain recognition) and properties of telecommand-telemetry system. When autonomous position finding systems are concerned, usually results of position defining algorithm are: azimuth refering to the GCS, slant distance between GCS and UAV and height of UAV above sea level barometric (or above terrain radar altimeter or elevation of UAV). As it is known from radar technique, distance measurement relative error is about three orders of magnitude less than angle measurement relative error [2], unless special methods are applied, while the complexity of appropriate methods is inversely proportional. This is the reason of great importance of angle measurement algorithm in position finding process as a part of autonomous position finding system.

Choice between applying global or autonomous navigation system usually depends primarily on intended operational range and possibility of direct communication between GCS and UAV.

In the case of using already existing telemetry and telecommand chanels (equipment) in UAV-GCS communication system for position finding such as in this particular case, characteristics of that equipment together with chosen operating frequencies of telecommand and telemetry (due to known dependency of effects of atmosphere on characteristics of electromagnetic waves propagation) limit range of operation. At the same time they make possible reliable position finding of UAV during all phases of flight, which is described in more detail in [3].

Angular position finding method based on monopulse receiver principle applied in above mentioned UAV-GCS complex deserves more detailed description because of its elegance, reliability and at the same time very good cost over performance relationship [3].

Communication system of UAV-GCS consists of ground equipment signal receiver) and airborne part (telecommand receiver and appropriate antenna systems both on UAV and

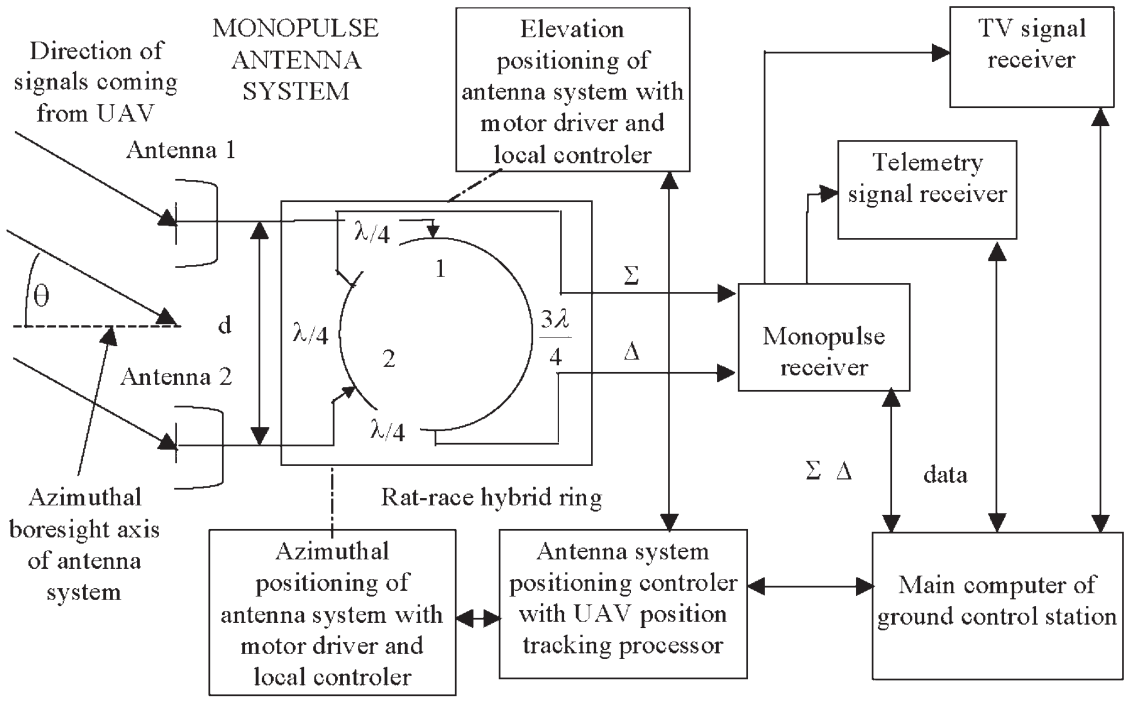

Fig. 1. Realized monopulse receiver without reference channel

GCS ([1], [3]). It connects GCS main computer and UAVs control computer, performing at the same time additional function - finding UAVs position: distance and azimuth angle while basic communication function is performed. Third coordinate height above sea level is obtained from barometer altimeter in UAV and sent to GCS via telemetry message. The distance finding system is based on application of secondary radar principle [4], and realization is described in detail in [5].

III. Monopulse Receiver

There are three basic classes of detection of angle θ č between boresight axis of monopulse antenna system and direction of arrival of signal from UAV: amplitude of arriving signal detection and comparison, phase of arriving signal detection and comparison and sum-and-difference of arriving signals [6]. Monopulse receiver configuration of the third class which is the most insensible to interference signal is depicted at Fig. 1. As it can be seen signals from two antennas (ie antenna arrays) are fed to special microwave unit - hybrid ring known as ”rat-race” in dielectric substrate technique or ”magic-T” in waveguide technique, which has two outputs. Because of the physical shape of this unit (distances between ports - two inputs and two outputs) it has special properties. At the one output of that unit signal is equal to the difference (designated as $\triangle$) of the input antenna signals, while at the other output signal is equal to the sum of the antenna signals (designated as Σ). It is known in literature (for example [6] where its functioning is elaborated in detail, as well as mathematical model) that angle θ defined at the beginning of this section depends on above defined signals $\triangle$ and Σ. Those signals are, generally speaking, complex signals, ie have components in phase - denoted by subscript I, and in quadrature – denoted by subscript Q, referring to the phase of the local oscillator (LO) as the part of the demodulator in the receiver.

Existence of components of the signals which are not in phase with appropriate basic signal are a measure of uncoherence of these signals with signal of the local oscillator and imperfections of parameters of receiving chains in $\triangle$ and Σ branches of monopulse receiver (as a consequence of differences of parameters characteristics which are unequal changed with change of frequency or temperature for example). It means that in the case of the coherent receiving process signals $\triangle$ and Σ signals have the same phase relationship to the incoming signal as to the signal of the receivers local oscillator. In one plane (in this case azimuthal) dependance between angle of incidence of the incoming signal and boresight axis θ and electrical signals in receiver is described by the following equation:

$$\theta = \mathrm{Im}\{\triangle/\Sigma\} = (\triangle_Q \Sigma_I - \triangle_I)/({\Sigma_Q}^2 + {\Sigma_I}^2)\ . \qquad (1)$$

When received signal and local oscillator are strictly in phase (quadrature), some of their components disappear (their projections on appropriate axes are zero) so expression becomes simply:

$$\theta = \triangle_Q/\Sigma_I\ . \qquad (2)$$

Using this fact monopulse receiver with proper operating mode (signals $\triangle$ and Σ in quadrature) is used for incidence angle measurement. Using normalization of the signals by Σ_I, it is enough to measure amplitude of $\triangle_Q$ signal to define angular position of the incidence signal according to the boresight axis, and sign of the angle is defined by the sign of $\triangle_Q/\Sigma_I$ ratio. Of course, this assumption is valid only for relatively small angles, because phase difference ϕ of inci-

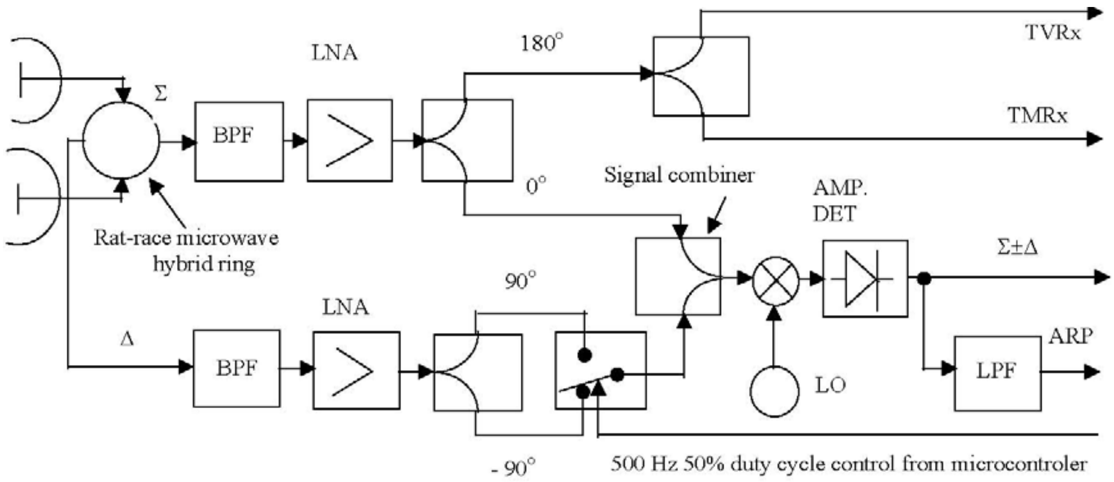

Fig. 2. Realized monopulse receiver without reference channel

dent signals coming to two antennas forming monopulse receiving system is sinusoidal ie periodical function of incident angle θ defined at the beginning of this section:

$$\phi = (2\pi \mathrm{d}/\lambda) \sin\theta \ , \qquad (3)$$

where d is the distance between centers of the antennas and λ is wavelength of incoming signal. This relation shows that phase difference is equal to 0 not only when θ is 0, but every time $\theta = k\pi$ (radians).

IV. Realized Monopulse Receiver without Reference Signal Channel

Because of fluctuations of receiver branches parameters additional reference channel is usually used to suppress their unwanted effects, and additional circuitry adds complexity to the receiver [7]. This increases price and efforts in maintenance, so it is motive to introduce another, new type of monopulse receiver, originally developed and realized. This new monopulse receiver is depicted on Fig. 2.

As can be seen from the picture, sum signal is splited after amplification in two parts. One part is with reversed phase and it is further splitted in two in phase components which are fed to the receiver of TV signals (as signal of mission equipment) and to the receiver of the telemetry signals. Another sum signal from the first splitter is fed to signal combiner.

Difference signal is after amplification fed to another signal splitter with two outputs. One output is difference signal phase shifted by 90° in advance, and the other output is the same signal only with phase delayed by the same amount. These two output signals are fed as inputs to multiplexer with periodical command signal (periode 2 ms, duty factor 50%), generated by microprocessor supported monopulse receiver controller, that choses which one of the two inputs is fed to the output. In that way, bearing in mind that $\triangle$ signal originally at the place of generation is in quadrature with Σ signal, at the output of multiplexer is alternation of difference signal which is in phase with sum signal and difference signal which is in phase opposite to sum signal. This output signal of the multiplexer is fed to earlyer mentioned combiner, so output of the combiner is alternatively once $\Sigma + \triangle$ and $\Sigma - \triangle$.

After mixing of the output of the combiner signal with the receivers local oscillator signal, at the output of the mixer we get alternation of sum+difference and sum-difference signals in baseband, which are fed to input of analog to digital converter synchronously with the above mentioned periodical command signal of multiplexer.

Intensity of the phase difference signal ie intensity of the incident angle of the received signal is obtained by simple arithmetic operation of summing the digital representatives of $\Sigma + \triangle$ and $\Sigma - \triangle$ signals and dividing the result by two in microprocessor. The sign of the phase difference $\triangle$ ie the indication is the incident angle of the incoming signal at the left or the right side of boresight axis of antenna system is obtained by comparing the phase of periodic multiplex command signal and the phase of $\triangle$ signal (difference of input antenna signals).

Data describing position of the UAV (distance, azimuthal angle) microprocessor controller of the monopulse receiver sends to main computer of the ground control station every 100 ms. During one period of the multiplexer command signal (2 ms), several measurements (AD conversions) are performed and the results are averaged in microcontroller to suppress noise, and only after filtering are sent to main computer.

Having in mind dynamics of flying object and electromechanical piedestal for antenna system, this velocity of obtaining data about UAVs position is quite satisfying. The whole applied algorithm of finding angular position by use of simple monopulse microprocessor supported receiver is laboratory and field tested and compared to other, more complex algorithms (with reference channel) also developed and realized by IMTEL institute and gave comparative advantages.

V. Conclusion

Simple, yet effective, reliable and low cost monopulse microwave receiver is designed and realized for autonomous angular position determination of unmanned aerial vehicle. Thanks to microprocessor supported functioning and special configuration, common used receivers reference channel is avoided as well as cumbersome and time consuming trimming of receiver parameters. The design is laboratory and field tested as a part of UAV-GCS complex with good results.

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