Pulse altimeter for aircraft

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Abstract. The paper discusses the methods for measuring the flight altitude of aircraft and the design features of pulsed radio altimeters. The results of model experiments in measuring the height by a pulsed radio altimeter are given.

1. Introduction
Measuring the flight altitude of aircraft (AC) above the earth’s surface is important for flight safety. The problem of low-altitude flights of unmanned aerial vehicles is the need to fly close to objects that create emergency situations during flights. Such objects are wave crests, trees, residential and industrial buildings, steep hills, etc. For flight in a changing terrain and to perform assigned tasks, aircraft are equipped with control systems that control the flight in accordance with a given program or by radio control signals. The current information on the flight conditions of the AC control system is provided by the measuring complex, which includes the vertical motion parameter meter - a flight navigation instrument for measuring the flight altitude of aircraft, which is called an altimeter.

Problems for accurate measurement of flight altitude, including unmanned, create dynamic changes in the terrain of the earth during flight, as well as the effect of the roll and pitch of the aircraft. The choice of a specific method for measuring altitude, especially for high-speed unmanned aerial vehicles, is not great. This is due to the fact that little is known about height measurement methods and they all have certain drawbacks that limit their use for high-speed aircraft. This article will briefly review the known methods for measuring altitude, propose an algorithm for the operation of a pulsed radio altimeter, and present the results of its application.

2. Methods of measuring flight altitude
There are several methods for determining the flight altitude of the aircraft. They differ in the principles and algorithms of altimeter operation. Typically, altimeters are divided into radio and barometric devices [1]. Barometric methods for measuring altitude by atmospheric pressure, decreasing with increasing altitude, are used extensively. For example, in airplanes, a barometric altimeter is successfully used. It determines the altitude of the flight relative to sea level, or relative to a given altitude level. The principle of operation of such altimeters is to measure the pressure of the atmosphere, which decreases with increasing altitude. Such an altimeter actually measures not the altitude, but the air pressure converted into altitude. Barometric altimeters are widely used by parachutists. The height measurement is made in meters, as the available zero-height adjustment allows setting the ground level before each jump.
Barometric altimeters can be mechanical and electronic. Structurally, the mechanical barometric altimeter is a sealed tube with a membrane (pressure sensor) associated with an arrow moving around the scale, scaled in meters of height. As the pressure changes, the membrane changes its position and moves the arrow. The electronic barometric altimeter also has a similar sensor, the mechanical signals of which are converted into a digital code and, after processing, are sent to the height indicator. The advantages of a barometric altimeter are that it is weather-proof and does not require orientation in space relative to the earth's surface. There are many constructions of barometric altimeters, but methods for measuring altitude from changes in air pressure give elevation values relative to sea level, which requires an accurate reference of the aircraft to the coordinates of the site that change during flight [1]. Another disadvantage of barometric altimeters is the inertia of the pressure sensors, which is unacceptable for high-speed aircraft. Because of these shortcomings, barometric altitude measurement methods are unacceptable for high-speed and low-flying aircraft.

Another method for measuring the AC flight altitude is based on the use of a laser. The principle of operation of such altimeters is quite simple and consists in the use of two laser signals emitted to the earth at an angle to each other. These signals create two patches of light on the earth's surface, the distance between which is proportional to the flight altitude of the aircraft. Fixing the spots of light by a digital video camera is not difficult to determine the height, since it is proportional to the number of pixels between the spots of light on the screen of the video camera. Such a method can be successful over the flat surface of the earth, but requires strict orientation of the emitting lasers over its surface. The method works poorly on the water surface, as well as in conditions of haze, fog, rain and hydrometeors. It limits their use for AC.

To form commands for soft landing of spacecraft at meter heights from the earth, gamma-ray altimeters operating according to the location principle are used. In such altimeters, radioactive Cobalt-60 or Cesium-137 isotopes are usually used, and the receiver determines the photon reflection from the underlying surface. Gamma-ray altimeters are used at low altitudes (meters and tens of meters from the surface), they have high accuracy and resistance to interference. Such altimeters do not require orientation relative to the earth's surface. Since the gamma-ray method works successfully only near the surface of the Earth, the method is not suitable for aircraft at altitudes of hundreds of meters, because it requires powerful radiation which is dangerous for people.

Radio altimeters (RA), applied to measure the flight altitude of an aircraft, also use the basic principle of radar based on determining the time of radio signal passage from the antenna of the RA radio transmitter to the reflecting underlying surface and back from the underlying surface to the RA receiving antenna [2]. The basis of the RA action is the reflection of electromagnetic waves emitted by the altimeter transmitter from the earth's surface.

The AC flight height when using the radio principle of determining the height is found from the expression:

\[ h = \frac{tC}{2}, \]

where \( h \) is height; \( t \) is the delay time of the received signal relative to the transmitted one; \( C \) is propagation velocity of radio waves, which is close to the speed of light in the atmosphere.

Methods for determining the delay of the RA signal are divided into pulsed and frequency ones. When using pulse signals, the time interval between two pulses is measured which are sent by the RA transmitter and reflected from the Earth, received by its receiver. When using frequency methods, the RA transmitter continuously emits a modulated radio signal with linear frequency modulation using saw-tooth or triangular pulses, and the RA receiver gets both transmitted and reflected signals from the underlying surface. At the input of the RA receiver when mixing the emitted and received signals, beats are formed with a frequency equal to the difference of the instantaneous frequencies and proportional to the \( t \) delay. The beat frequency is measured by a frequency meter and determines the distance to the ground.

Frequency methods for measuring the AC flight altitude have several disadvantages, namely: continuous-action radio altimeters require separate and spaced antennas for the transmitter and
receiver of signals; continuously operating RA transmitter consumes a lot of energy; RA weight and dimensions are large due to the weight of analogue equipment and two antennas.

Pulse altimeter (PA) can use one antenna, alternately used by the transmitter and receiver and connected via a circulator. The pulse method of measuring the height gains significantly because of the low power consumption of electricity from the power source in a pulsed mode.

The size of the underlying surface area illuminated by the PA pulse depends on the magnitude of the antenna gain, on $h$ flight altitude, $\beta$ roll angle and $\gamma$ pitch of the AC flight. In this case, RA illuminates a platform on the earth’s surface in a form close to a circle, and the size of the area reflecting the radio pulse of the RA transmitter can be defined by the expression:

$$S = \pi (h \cdot \cos \beta \cdot \cos \gamma \cdot \tan \frac{\alpha}{2})^2,$$

where $\alpha$ is opening angle of the main lobe of the PA antenna pattern.

It is not difficult to show that the size of the reflection area is much larger than the PA wavelength and the signals reflected from different parts of this area will come to the PA receiver with different amplitudes and phases, which will lead to interference of the signals at the input of the PA receiver [3]. As a result of the multipath of the received PA signals, fading occurs, reducing the likelihood of correct reception of the radio pulse [4-5]. It requires an increase in the power of the radio pulses of the transmitter, but taking into consideration the high porosity of the radio pulse sequence emitted by the transmitter, it does not increase the average power consumed from the PA power source.

3. The algorithm of the pulse altimeter operation

The algorithm of PA operation can be summarized as follows:

1. Starting a microwave generator with $f_n$ carrier frequency.
2. Starting the generator of modulating pulses of $t_i$ duration and $T_i$ period of repetition.
3. Starting the generator of counting pulses with $t_s$ duration and $T_s = 2t_s$ repetition period.
4. Amplitude modulation of a microwave signal by a modulating pulse of $t_i$ duration and $T_i$ repetition period.
5. Radiation of a radio pulse by a microstrip antenna array of $t_i$ duration with $f_n$ frequency of filling.
6. Resetting a high-speed digital counter on the leading edge of a radio pulse emitted by an PA transmitter with $t_i$ duration.
7. Waiting for the termination of the emitted radio pulse of $t_i$ duration.
8. Starting a high-speed digital counter with a repetition period of $T_s$ counting pulses on the trailing edge of the emitted radio pulse of $t_i$ duration.
9. Waiting for the arrival of the reflected radio pulse and its detection.
10. In the presence of a reflected pulse - stop of the counter at the command of the comparator.
11. Writing the result to the memory register.
12. Data transfer to the information processing unit through standard digital information transfer interfaces.
13. When the waiting time is exceeded and the value of $T_i - nT_s$ (where $n>1$) is reached (, a special value is written to the memory register and then a special value is transmitted to the information processing unit, which should be understood as “no reflection”).
14. When the waiting time of the value of $T_i - T_s$, the counter is reset.
15. Go to paragraph 5.

The repetition period of $T_s$ counting pulses determines the accuracy of the measured altitude of the flight of the unmanned AC and depends on the choice of the element base of the high-speed counter and the scheme of the generator of counting pulses. The values of the measured height are calculated by the formula:

$$h = h_{\text{min}} + \frac{CZT_s}{2},$$
where \( Z \) is the number determined by the readings of the high-speed counter, \( C \) is the propagation speed of radio waves, \( h_{\text{min}} \) is the minimum allowable AC flight height.

The information processing unit should receive digital data from a high-speed counter. In general, the information processing unit should perform the following operations:

- To filter out special values that signal the absence of a reflected signal and issue an “error” signal;
- To make a correction of the data, multiplying the values obtained by the cosines of the angles of roll and pitch taking into account the signs of these angles, getting the values of these angles from the three-position electronic gyroscope;
- To average the data obtained for several consecutive measurements (from 3 to 5), which will allow not to take into account the possible yaw on the aircraft course due to wind loads and pressure drops [6];
- To generate a signal about the minimum allowable flight altitude of the aircraft and feed it to the flight control devices for decision making;
- To issue the processed information about the altitude of the flight to the output of the PA on one of the standard digital data transmission interfaces.

Depending on the purpose of the PA, the data obtained may be used for indication, transmission to the ground, for flight control or other purposes.

4. Results of the simulated experiments
To study the possibilities of the proposed algorithm in C++, a program was developed and experiments were conducted. As a model of the underlying surface of the sea and land, a sinusoid was used, with the help of which the height of possible obstacles to flight was simulated, and the length of the obstacle was simulated using a sinusoid period. The experiments were carried out for different \( h \) AC flight altitudes and for various \( V_{AC} \) flight speeds. AC flights moving both smoothly and with different \( \beta \) heel angles and \( \gamma \) pitch were simulated.

Figure 1 shows the simulation results of AC flying at a speed of 700 m/s at an altitude of 30 and 200 meters relative to the base of the hills, with roll and pitch angles of up to 15° and \( P \) probabilities of missing measurements. The thick line in the figure shows the surface from which \( h \) flight height is measured. The difference between the thick line and the underlying surface shows the magnitude of the measurement error of the AC flight altitude. In this case, the measurement error does not exceed the specified emergency altitude with a low flight altitude, and the PA shows a flight altitude value less than the real error, which gives AC an additional margin from the emergency distance to the ground [6].

![Figure 1. Measurement of altitude in different conditions of AC flight.](image-url)
Model experiments have shown that the measurement error at angles of pitch and roll is not more than 25°. At AC speeds from zero to several supersonic it will be determined by the expression:

\[ h = h_{min} + 0.02h. \]

The value \( h_{min} \) depends on the repetition frequency of PA counting pulses and on the speed of the counter of these pulses. Experiments have shown that with a frequency of counting pulses of 300 MHz and AC speed of up to two supersonic skips of up to 70% of measuring pulses, it practically does not affect the measurement accuracy.

5. Conclusion
The proposed algorithm of radio pulse measurement of the AC flight altitude allows measuring the height quickly when flying over a flat and over a very hilly terrestrial surface, as well as over a calm and stormy sea. However, the accuracy of measurements over hilly terrain with increasing roll, pitch and flight altitude somewhat decreases due to the increase in the area of reflection of radio pulses. Also, the accuracy of measurements decreases with increasing sharpness of the hills of the earth's surface. The advantage of the proposed algorithm is that the PA shows the flight altitude always by an amount less than the real error, which protects the aircraft from emergency situations.

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