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RADAR-ALTIMETER IN THE FUNCTION OF ANTICOLLISION SYSTEM

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ABSTRACT

The paper presents the possibility of applying classical onboard aviation radar-altimeter in the function of a simple anti-collision system. At present, classical radar-altimeter offers two important pieces of information for the pilot, actual flight altitude and aircraft decline on the level of decision making.

By the application of relatively simple complementary circuit into this avionic system, radar-altimeter can be used for the creation of a new piece of another – new information.

It is an essential piece of information for the pilot and it can be presented as prediction of the threat of aircraft collision or a helicopter collision into the terrain.

The paper is devoted to possible way of evaluation of basic piece of information, Doppler frequency in radar-altimeter, which can be used for above mentioned prediction system. To prove this theory, actual helicopter flight in rough terrain has been performed. The paper offers presented results of measurements of Doppler frequency of radar-altimeter during mentioned flight.

Future operations of such add-on avionics device might lower CFIT (controlled flight into terrain) accidents and is an affordable solution for increased safety of TAWS (Terrain Awareness and Warning System) units.

INTRODUCTION

Recent development of air transport, using new technologies and openness of air traffic legislation, enables the airlines to produce quality small aircrafts and helicopters. Recent air traffic can be a potential source of different collisions and disasters.

The producers of aircrafts strive to equip every aircraft and helicopter with such assistance information system, which would be able to avoid any collisions or disasters in advance [7].

Such disaster can be for instance the collision of the aircraft into the terrain, also called CFIT (Controlled Flight Into Terrain). Recently this problem has been quite successfully solved in big airliners by implementing EGPWS system (Enhanced Ground Proximity Warning System).

For small aircraft and helicopters, however, this system is financially rather demanding. Due to this fact nowadays, there no exists signalization device able to solve such flight situations securely on small aircrafts and helicopters [1, 2, 3, 8].

When flying a helicopter at a low altitude, if pilot for unforeseen reasons cannot see the ground, he has got only a radar-altimeter at his disposal, which at the moment evaluates the real altitude above the terrain.

Although radar-altimeters can have the so-called "dangerous height" adjusted, but signalizing this altitude seems to be insufficient under such conditions [5, 6, 9].

It would be much more advantageous to have a device which would warn against the collision with the ground ahead of time under the above-mentioned circumstances.

Helicopter, in fact, is a specific machine (pendulum), which serves for the movement in indented terrain in small heights, where the potential danger of collision into terrain is too high. Controlled flight into terrain is mostly caused by the fact that the land surface is covered by clouds or darkness at night, which worsens visibility and pilot's orientation [4].

The paper deals with possible solution of a simple anti-collision system for small aircrafts and helicopters, which would enable to increase helicopter flight safety during the flight in small heights in indented terrain. It shows that such function could be fulfilled by an altimeter after certain adjustment of electronic circuit solution, working with frequency modulation.

DOPPLER EFFECT IN RADAR-ALTIMETER

Radar-altimeter of small altitude working in FMCW (Frequency Modulated Continuous Wave) regime belongs among the basic navigation systems of nearly every aircraft or helicopter.
Classical altimeter recently offers two important pieces of information for the pilot.

The first one is presented by continuous value of immediate altitude of the flight and the second one is presented by a discrete announcement during the drop of the aircraft or helicopter to the level of decision height.
By theoretical analysis of the radar-altimeter differential frequency creation it is possible to consider that the radar-altimeter is a potential source of possible creation of the third piece of information, which can be used for the prediction of the collision of the aircraft or helicopter into the ground.

Radar-altimeter with frequency modulation creates, as a result of dynamic change of altitude, additional value of frequency to the original differential frequency. This additional value of frequency shapes as a result of Doppler effect during the descend and increase of the terrain.

In this case the resulting frequency is shaped by radar-altimeter F_{rD} created by adding the original differential frequency F_r and additional Doppler frequency F_D:

$$F_{rD} = F_r + F_D = \frac{8\Delta f \cdot F_M}{c} H \pm f_0 \frac{2v_V}{c} \text{ . (1)}$$

Where:

- F_{rD} – resulting frequency shaped by radar-altimeter,
- F_r – differential frequency of radar-altimeter corresponding to helicopter's flight altitude,
- F_D – differential frequency of radar-altimeter corresponding to Doppler effect,
- Δf – frequency deviation,
- F_M – frequency modulation,
- H – helicopter flight altitude,
- f_0 – center frequency sweep of radar altimeter,
- v_v – vertical component of speed,
- c – speed of light.

In Figure 1 there is a double frequency shift of received signal in comparison with the transmitted one:

a) shift in time (to the right), as a result of time delay in value τ,
b) shift in frequency (upwards), as a result of Doppler effect in value F_D.

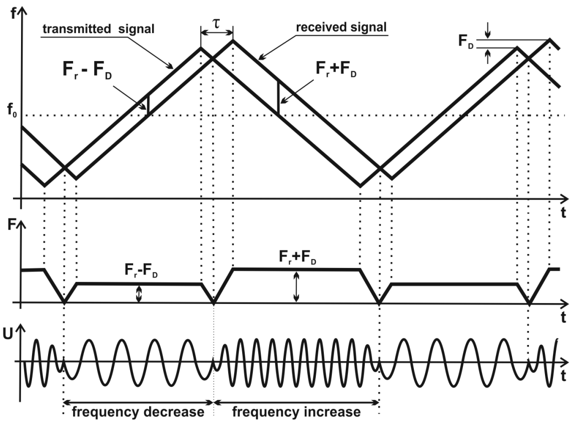

Figure 1: Influence of Doppler effect on the creation of differential frequency F_D

From Figure 1 it is obvious that if the frequency modulation has a shape of symmetric saw, then in one half-period of modulation frequency the differential frequency under the influence of Doppler effect grows and in the second half-period it decreases.
When classical evaluation of differential frequency is used, this occurrence is eliminated in a simple way.

It is possible to create anti-collision system for small aircrafts and helicopters by the realization of relatively simple additional electronic circuit board of the radar-altimeter, which would be able to evaluate Doppler frequency and compare it with the frequency corresponding with the flight altitude.

THEORETICAL PRECONDITIONS OF HELICOPTER ANTI-COLLISION SYSTEM

Let us suppose that the helicopters is flying on a constant flight level in altitude H above the terrain and that from certain point A the terrain starts approaching the flying aircraft, see Figure 2.

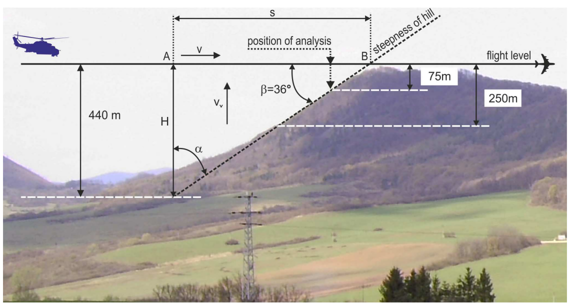

Figure 2: Determination of the time collision of the aircraft into the terrain

The collision of the aircraft into the terrain would occur in point B in time t, when the helicopter finishes the route s.

This leads to:

$$t = \frac{s}{v} = \frac{H \cdot tg\alpha}{v}, \tag{2}$$

where:

s – distance flown,
v – the speed of aircraft flight,
α – terrain inclination angle.

When approaching terrain, Doppler frequency F_D is shaped, which is adequate to vertical element of speed v_v. Vertical element of speed is according to Figure 2 given by the relation

$$v_v = \frac{v}{tg\alpha}, \tag{3}$$

and consequently

$$t = \frac{H}{v_v}. \tag{4}$$

The parameters of this relation are the flight altitude H and vertical element of speed v_v.

The aircraft flight altitude H is evaluated by classical radar-altimeter and it is given by the value of differential frequency F_r. Classical radar-altimeter changed measured value of differential frequency F_r corresponding the altitude and voltage U_H corresponding the altitude.

Vertical element of speed v_v corresponds the value of Doppler frequency F_D. To determine the dangerous period of time it is necessary to change also the value of Doppler frequency F_D corresponding to the vertical element of speed to the voltage U_D corresponding to the vertical element of speed.

The state when the two voltages in the relation (5) reach certain ratio is determined by the time, which remains until the collision of the aircraft into the terrain. Deduced value of time t (4) until the collision of the aircraft into the terrain can be marked as the time of approaching disaster t_k, which corresponds the ratio of frequencies or voltages (5).

$$t_k \approx \frac{F_r}{F_D} \approx \frac{U_H}{U_D} \tag{5}$$

By the adjustment, evaluation and signalization of certain ratio of given voltages values it is possible to pre-set the time t_k, which remains until the collision of the aircraft into terrain, on the condition of maintaining the original flight parameters. This creates certain time reserve for the pilot to divert such disaster.
As the information about the altitude is included in the radar-altimeter, it was necessary to evaluate to which shape Doppler frequency shapes the radar-altimeter to check the effect of this theory.

As Doppler frequency is shaped in the flight regime only during dynamic altitude change, two ways of its evaluation have been realized. The first way has evaluated Doppler frequency by the simulation and the second one by experimental measuring.

SIMULATION OF DYNAMIC CHANGE OF HELICOPTER FLIGHT ALTITUDE

For the simulation of dynamic change of helicopter flight altitude a model of radar-altimeter version (RV-5) has been created. The input parameters for the simulation have been

– frequency deviation Δf = 50 MHz ,
– modulation frequency F_M = 150 Hz,
– helicopter flight altitude H = 73.3 m,
– center frequency sweep f_0 = 4.4 GHz,
– flight speed v = 150 km/h,
– hill inclination β = 36.5 º.

Parameters of this dynamic change have been defined by the inclination of virtual hill, flight altitude and flight speed.

In Figure 3 the results of simulation are presented, i.e. the dependence of differential frequency F_r on simulation time.
By dotted line, differential frequency evaluated by the radar-altimeter, from which radar-altimeter indicated altitude.
Full line presents real value of differential frequency in dynamic altitude change.

As Figure 3 shows, it can be seen that in first half-periods of modulation frequency, the value of differential frequency is lower (approx. under 14 kHz) in the value of Doppler frequency, the value of which depends on the vertical element of speed.

In the second half-periods of modulation frequency the value of differential frequency is higher (approx. under 16 kHz) in the value of Doppler frequency. As the value of vertical element of frequency, according to equation (3), equals v_v = 30.84 m.s^{-1}, then the value of Doppler frequency with the simulation equals F_D = ±905Hz.

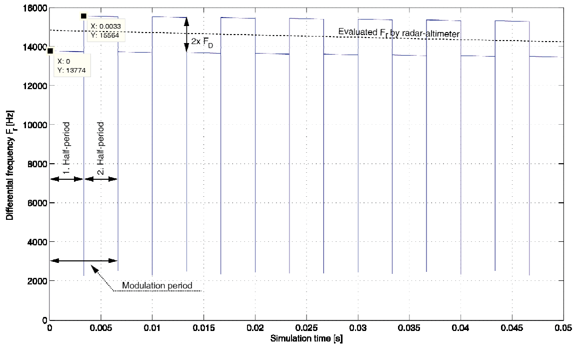

Figure 3: Dependence of differential frequency F_r on simulation time with dynamic altitude change

EXPERIMENTAL MEASUREMENTS OF DYNAMIC HELICOPTER FLIGHT ALTITUDE CHANGE

The aim of the experiment has been to verify and analyze the creation of Doppler effect of radar-altimeter during horizontal flight of the helicopter over the terrain, the relief of which rises dangerously.

For the verification and analysis of the creation of Doppler signal F_D, time recording of signal F_r lasting 73 seconds has been made, see Figure 4.

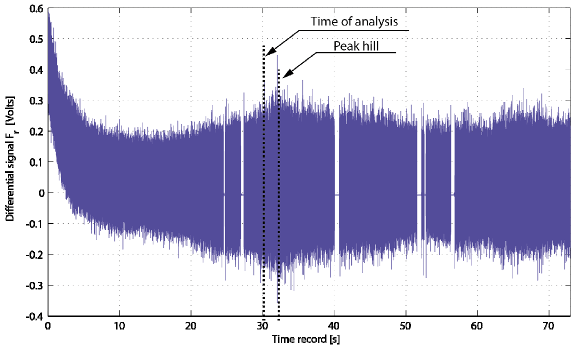

Figure 4: Record of differential frequency after flying over the hill top

The differential frequency of radar-altimeter corresponds with measured aircraft flight altitude in the range from 250 m (mid-hill) up to 15 m (over the hill top).

Time area of the record, which has been analyzed for frequency, corresponds with time approx. 30 seconds.

During helicopter flight over the hill top, when the flight altitude was the smallest, the amplitude of the differential signal was the greatest. According to the record, the helicopter flew over the hill top in the time 32 seconds from the beginning of the record, see Figure 4.

For the purpose of evaluation of Doppler frequency F_D frequency analysis of differential signal F_r in each half-period of each different modulation signal has been made.

Time period of one period of a modulation signal has been selected for this paper, see Figure 5.

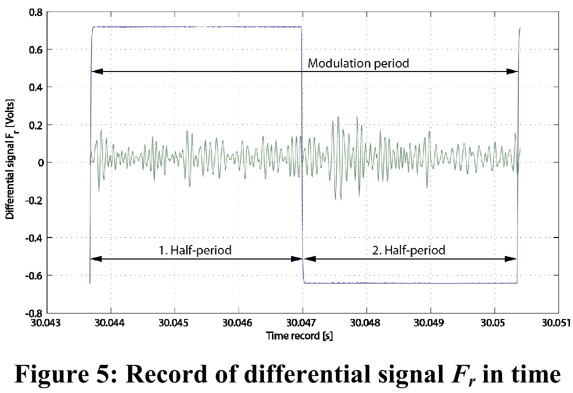

Figure 5: Record of differential signal F_r in time period of one modulation period

According to frequency analysis:

1) the basic harmonic component of differential signal from time section of first half-period of modulation frequency F_M is the frequency of 15,6 kHz,
2) the basic harmonic component of differential signal from time section of second half-period of modulation frequency F_M is the frequency of 13,74 kHz.

Frequency difference of two given basic harmonic differential signals is 1860 Hz.

The value 1860 Hz presents double Doppler frequency $F_D = 930$Hz.

By measuring differential signal during the helicopter flight into the hill and consequent spectral analysis of this signal it has been concluded that the differential signal of radar-altimeter F_{rD} includes (under these flight conditions), besides the frequency corresponding the aircraft flight altitude F_r also Doppler frequency.

This theoretical precondition has been verified by realized experiment.

The speed of helicopter flight during realized experiment has been 150 km/h. This value corresponds horizontal element of speed $v = 41.67$ m/s. Using the function of tangent of known value of angle β and horizontal element of speed v it is possible to calculate vertical element of speed $v_v = 30.84$ m/s.

By the implementation of this value into the relation (1) we can calculate Doppler frequency F_D. The calculated value of Doppler frequency 905 Hz is comparable to the measured value of Doppler frequency 930 Hz.

CONCLUSIONS

Onboard aircraft radar-altimeter is a part of avionic equipment of nearly every small aircraft as well as helicopter.

During helicopter flight over the terrain, which has dangerous vertical distance, creates also Doppler frequency as a side product during the creation of differential frequency of radar-altimeter. Doppler frequency F_D corresponds vertical element of speed v_v, which can be used for determination of the time of the collision of the aircraft (helicopter) into the terrain.

From the analysis it is obvious that for determination of time of the collision of aircraft (helicopter) into the terrain it is necessary to evaluate voltage corresponding with differential frequency to the voltage of corresponding Doppler frequency.

The time until the collision can be evaluated by a simple ratio of two voltages from the output of radar-altimeter.

This fact enables to create a relatively simple electronic circuit solution of anti-collision system, which will inform the pilot of the threat of collision of the helicopter with the terrain in advance.

Radar-altimeter, as relatively simple avionic equipment, could fulfill also tertiary – prediction function, i.e. inform the pilot of the threat of collision, besides the information about the actual flight altitude and warning information about dangerous altitude.

Real value of Doppler frequency, which has been considered only theoretically so far, has been evaluated within experimental measurement on real helicopter over the real terrain. Measured results have corresponded theoretical presumptions quantitatively.
Given fact fulfills the idea that the solution of anti-collision system with the radar-altimeter is possible.

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