METHODICAL ERROR OF LOW ALTITUDE ALTIMETERS AND POSSIBILITIES OF ITS IMPROVEMENT

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This article is focused on the present state in the field of the accuracy of measurement of the real height of the aircraft above the terrain with a radioaltimeter. Authors deal with the analysis of beat frequency generation and also with the reasons of formation of the methodical error of radioaltimeter. On the base of those knowledge and findings this article also implies the solution and the attitudes to the improvement of the accuracy of radioaltimeter by reducing of the methodical error.

K e y w o r d s: radioaltimeter, methodical error, measurement of the period of beat frequency signal, extreme wide frequency band

1 INTRODUCTION

Continual progress of aeronautical techniques is still demanding harder standards on the control and navigation systems. An extra attention is devoted mostly to radio systems, which are designed to measure the fundamental parameters of aircraft movements (for example: height of the flight, vertical speed, real height of the flight, ground speed, etc.). Moreover, the equipment, which are able to detect and indicate those parameters are on board of the aircraft, very often the part of the more complicated ergatic systems. The common denominator of higher mentioned parameters’ are mostly the accuracy and reliability, what is the main essence for safety of the flight. Measuring of the real height of the flight above the terrain, is one of the most crucial indication, during the IFR approach, landing and throughout the flights at low levels above the terrain.

2 THE PRESENT STATE OF THE PROBLEM

At the present time are the most spreading type of the radioaltimeters of low altitudes, radioaltimeters Works with frequency modulation. The range of measured height is mostly between 0 ÷ 1500 meters. The baseline of advancement of radioaltimeters is focused on the increasing of accuracy and reliability, simultaneously with the reducing of the weight and size. Improvement in the accuracy is achieved by the use of new ways of creating and processing of the signal which is carried the information above the height of the flight. For the better imagination about the accuracy of those devices, we can show several examples of the various types of radioaltimeters. (Tab. 1)

3 ACCURACY OF MEASURING THE HEIGHT OF RADIOALTIMETERS

The accuracy of measuring the height is possible to define directly - by the parameter „ accuracy of measurement“ or indirectly by the errors, which distort the overall result of each measurement. Into the basic list of the errors of radioaltimeter belong: methodical error, error of Doppler effect, shift error, fluctuation of the signal, dynamic error, error of parasitic modulation, instrument error and error of instability of parameters FM.

METHODICAL ERROR

Methodical error is the fundamental and the most crucial error of the radioaltimeters work with frequency modulation. It expresses by the discrete change of output information during the continual change of the real height. The reason is the periodic character of the law of frequency modulation. The amplitude spectrum of the beat signal is discrete and includes just frequencies, which are the multiple of the modulation frequency F_M, whereby with increasing the height has become the spectrum of its signal more and more complicated. That fact degrades the fixing of the frequency depends on the height or the flight level.

It is assumed that the transmitter of the radioaltimeter is transmitting a high – frequency, frequency – modulated signal:

$$u_v(t) = U_v.\sin\left[\omega_o t + \frac{\Delta\omega o}{\Omega M}\ t\right], \qquad (1)$$

Type of radioaltimeter	Carrier frequency [MHz]	Frequency lift [MHz]	Modulation frequency [Hz]	Range [m]	Accuracy up to 10m [m]	Accuracy over 10m [m]
RV-UM	444	8,5	70	0-600	5	8
RV-3	2000	25	170	0-300	1	10
RV-5	4300	50	150	0-750	0,6	6
RV-15	4300	50	120-600	0-1500	0,6	6
KRA-405	4300	50	100	0-600	1,5	7

Tab.1 Review of basic parameters of selected radioaltimeters

where: $\omega_o = 2\pi f_o$ is the average value of the carrier radian frequence of the transmitter $\Omega_m = 2\pi F_M$, what represents radian modulation frequency, $\Delta\omega_o = 2\pi\Delta f_o$ is the carrier frequency lift, f_o middle transmitted frequency value, Δf_o transmitter frequency lift, F_M represents modulation frequency.

DETERMINIG THE CRITICAL HEIGHT VALUE OF ΔH

By the further analysing we get the finding that the maximum value of the initial phase φ_0 and the value of variable phase φ_M depend on the height of the flight. Instantaneous value of the phase Ω_M changes together with the time during the constant height. That fact results from the analysis of the phase relation. The number of pulses N, which are generated during one modulation period, at the constant height, depends on the number of crossing the modulation phase envelope φ_M with the zero line. The envelope is crossing the zero every π radians.

$$N = \frac{\varphi M}{\pi} = \frac{\frac{8\pi\xi}{\lambda o}H}{\pi} = \frac{8\xi}{\lambda o}, \qquad (2)$$

where: N – number of pulses.

From that reference (2) results, that the number of pulses within the one modulation period is directly proportional to the height of the flight of the aircraft. In the next text we deal with the fact, about what value is it inevitable to change the height for the increasing of the pulses about one stable pulse, during the one modulation period. It causes practically increasing the value at the indicator of the height. The specific number of pulses N_k for the desired height H_k is given by the relation(3) :

$$N_k = \frac{8\xi}{\lambda o}H_k \qquad (3)$$

We can assume that the number of the pulses increases about one permanent pulse if height H_k increases about the value ΔH. Thus, we can write (4):

$$N_{k+1} = \frac{8\xi(Hk+\Delta H)}{\lambda o} \qquad (4)$$

Out of the written relations (3), (4), we can derive the condition of the form of one permanent pulse:

$$N_{k+1} - N_k = 1 \qquad (5)$$

After the substitution, we can write:

$$\frac{8\xi(Hk+\Delta H)}{\lambda o} - \frac{8\xi}{\lambda o}H_k = 1 \qquad (6)$$

By the next adjustment, we get:

$$\Delta H = \frac{\lambda o}{8\xi} = \frac{c}{8\Delta f} = H_{min} \qquad (7)$$

where: ΔH is the minimum height, at which the form of one permanent pulse is $\xi = \frac{\Delta fo}{fo}$

Minimum height H_{min} is given by the relation (8):

$$H_{min} = \frac{c}{8\Delta f} \qquad (8)$$

where the value Δf is the amount of frequency lift and c represents the speed of spreading radio waves. That relation gives the minimum difference between the heights which can be measured as ΔH. We can call that value as a critical height, what represents the minimum change of the height, which can be registered by the radioaltimeter. Thus, as a result, if the aircraft changes its height about the value which is smaller than the value ΔH, the indication is not changing, because the number of permanent pulses within modulation period is still the same because the number of pulses does not change during constant modulation period. For various types of radioaltimeter the value of ΔH is also various.

4 APPROACHES TO IMPROVING THE METHODICAL ERROR OF RADIOALTIMETERS

There are more concepts of reducing of critical height and thus also the methodical error of radioaltimeter with frequency modulation. By analysing the characters of radioaltimeters we arrive at the conclusion that improvement in the accuracy of measurement can be achieved by:

a) massive increasing of the frequency lift,
b) innovative concept of processing the beat frequency.

Following the new cognitions in that issue and capability of new ways of realization of the experiments in laboratory conditions the situation has markedly changed. The attention is focused on analyse, design and realization of the experiments increasing of the frequency lift and finding innovative methods of evaluating the beat frequency. Expected areas of realization of radioaltimeters:

a) with the evaluation of the period of differential signal,
b) with the extreme wide band of carrier signal.

RADIOALTIMETER WITH THE EVALUATION OF DIFFERENTIAL SIGNAL

The baseline or idea of measure of the height by new method is to evaluate the period of differential signal T_r, because the change of the period is changing together with the height continuously. That continuous change is just in the range of half-period of modulation signal, because every modulation half-period is beginning by the turning of the phase of the differential signal about o 180°.

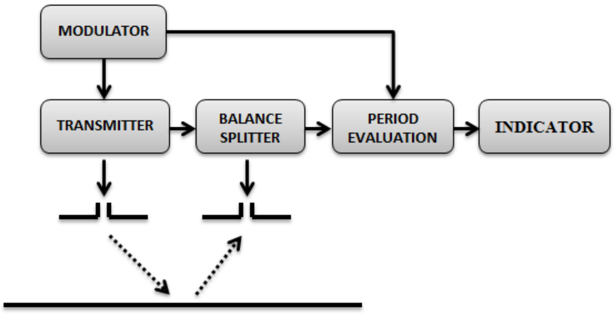

Figure 1 Simplified scheme of RALT with the evaluation of period the differential signal

By evaluating of the period of differential signal is including the keeping the advantages of wide band FM radioaltimeter, supressed the methodical error of radioaltimeter. Accuracy of the measurement of the height depends mostly on the way or quality of the processing the period of the modulation signal. Simplified scheme (Fig. 1) is shown almost the similar structure as a standard radioaltimeter, it is just supplements by the circuits for evaluation of the period of differential signal.

RADIOALTIMETER WITH EXTREMAL WIDTH OF THE FREQUENCY BAND

Methodical error of classical radioaltimeters is given by the relation (8). Noted value of Δf in that relation represents the frequency lift, which is varies around the middle value of carrier frequency $f_{o.}$ Maximum value of frequency lift is limited, mostly from the realization point of view, however we should deliberate also the possibility of forming the parasitic AM modulation after the overcrossing the limit value of the frequency band. Parasitic amplitude modulation is generated due to the non-constant transfer characteristics of the high frequency circuits and also due to non – constant gain of each antenna in all range of the frequency band. All that elements are tuned at the middle of that band and that is the reason why they have the less gain parameter on the both sides of the band. The eventuality of avoiding of the parasitic AM modulation is by two-times increasing of the origin frequency lift is to create the radioaltimeter with the two classical individual, in parallel high frequency channels K1 and K2. Simplified diagram of that type of radioaltimeter is in the picture (Fig. 2).

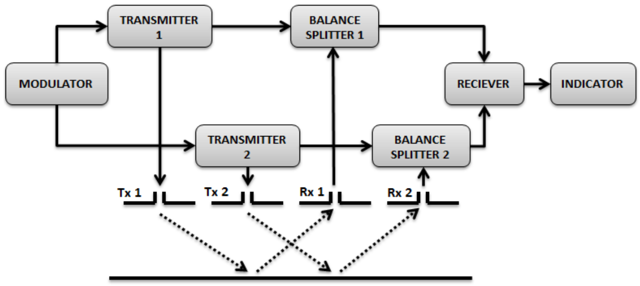

Figure 2 Simplified diagram of the radioaltimeter with extremely width of the frequency band

The width of the frequency band of classical radioaltimeter is:

$$B_{kl} = 2.\Delta f \qquad (9)$$

In case of radioaltimeter with extremely wide frequency band, we supposed, that its frequency lift Δf_{ext} has the value of B_{kl}

$$\Delta f_{ext} = B_{kl} = 2.\Delta f \qquad (10)$$

Thus, the value of bandwidth of radioaltimeter B_{ex} is:

$$B_{ex} = 2.\Delta f_{ex} = 2.B_{kl} = 4.\Delta f \qquad (11)$$

And this is 4 – multiple of the frequency lift of classical radioaltimeter.

Following the relation (8) for determining of methodical error of radioaltimeter with extreme bandwidth ΔH_{ex} will be its value given by:

$$\Delta H_{ex} = \frac{c}{8\Delta f ex} = \frac{c}{16\Delta f} = \frac{\Delta H}{2} \qquad (12)$$

This value is just the half of the methodical error of classical radioaltimeter.

5 CONCLUSION

Presented innovative methods of improving the methodical error keep the simplicity the origin frequency method of measuring the real altitude. The direct realization and followed verification of that assumption – verification of thesis, is a very complicated and difficult process. It results basically from the frequency spectrum of the differential signal, which is very complicated. If we fulfil the expectations, the contribution of our work will be in improving the radioaltimeter accuracy of measurement, without further increasing of the value of carrier frequency. In case of radioaltimeter it is achieved by the increasing of the value of frequency lift and on the second case, it will be achieved by the exact measurement of the period of differential signal. Both principles can markedly improve the methodical error of radioaltimeters, which in the end means improved safety of flights in the air transportation.

ACKNOWLEDGMENT

This work was funded by the European Regional Development Fund under the Research & Development Operational Programme project entitled "Construction of a research & development laboratory for airborne antenna equipment, ITMS: 26220220130."

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