Simple Vertical Velocity Measurement System for Different Use

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ABSTRACT

The measurement of vertical velocity is based on principle of evaluating the change of an atmospheric pressure. The dependence which evaluates the vertical velocity is derived from the exponential form of the barometric equation which relates the air pressure versus the altitude. This relatively simple method has some drawbacks. First of all it is a nonlinearity of the exponential dependency of the pressure versus altitude. Also the air temperature plays a significant role in this method. Compensated methods for measuring the vertical velocity embrace the vertical velocity correction. The correction is calculated from the horizontal velocity change which induces another vertical velocity change. The acceleration is evaluated in the horizontal direction using the information about the dynamic pressure. The solution is based on the altitude equation, including the effects of temperature. The possibility of nonlinearity compensation and temperature compensation are used. New assets are represented by the new electronic circuit blocks.

Keywords: pressure sensor, altitude, vertical acceleration, nonlinearity, barometric

1 INTRODUCTION

Information about the vertical acceleration is necessary for different use. We can use a several ways how to calculate the vertical velocity. The simple solutions are based on principle of calculation the change of a barometric pressure. The measurement is relatively simple method with some drawbacks, for example a nonlinearity of the exponential dependency of the pressure versus altitude. A significant role plays also the air temperature. The vertical acceleration measurement is typically method used in devices that measure the air planes rising or falling.

Compensated methods for measuring the vertical acceleration are used. The compensation and correction are calculated from the horizontal velocity change. The acceleration is evaluated in the horizontal direction using the information about the dynamic pressure [3]. It means that the acceleration (kinetic energy) is converted to corresponding change of the altitude (potential energy). Vertical acceleration can be corrected by this value.

No-compensated simple methods are based on measuring the vertical acceleration (by velocity) using the information about the change of the static barometric pressure. The absolute air pressure values are measured in regular time. The barometric pressure difference related to the time interval determines the vertical acceleration (velocity).

2 PRINCIPLES

The principle is described in [1]. The vertical velocity is derived from the exponential shape of the barometric equation (one relates the air pressure versus the altitude)

$$p(z) = p_o e^{-\frac{z}{z_o}}, \qquad z_o = \frac{kT}{gm_o} \tag{1}$$

where p_o is the sea level altitude air pressure, p(z) is the barometric pressure in altitude z, T (K) is the temperature, other elements are constants, m_o (-), g ($m \cdot s^{-2}$), k ($J \cdot K^{-1}$). The element e^{-z} can be written in the Taylors polynomial shape. Omitting the powers from this formulation bigger then one, it can be written

$$\frac{dz}{dt} = -\frac{z_o}{p_o}\frac{dp(z)}{dt} \tag{2}$$

If the air pressure sensor with the voltage output v(p) is used and if the output voltage is direct proportional to the barometric pressure p(z) it can be obtained simple formulation for the vertical velocity in the shape

$$\frac{dz}{dt} = -\frac{z_o}{p_o}\frac{dv(p)}{dt} \tag{3}$$

where v(p) is the sensor voltage output. Dependency according the equation can be realized using the differentiator. Non-linearity compensation can be done using the circuit with the inverse characteristic (logarithmical circuit). The temperature compensation is essential to solve as well. The circuit solution can be done by temperature compensated (pn junction in the shape of diode) logarithmic circuit which realizes linearization of the input exponential voltage. Following circuits are the amplifier and the differentiator. There can be expressed the output voltage from the simple differentiator with the feedback diode in the shape

$$v_2 = -\frac{kT}{q} ln \frac{v_1}{Ri_s} \qquad (4)$$

where i_s represents the current given by the diode technological parameters and R is the input resistor of the differentiator. Transfer characteristic according (4) depends on the temperature. The characteristic have the voltage shift c for different temperatures. The temperature dependency for the current i_s causes small distortion. Output voltage can be expressed in the shape

$$v_2 = f(v_1) + c \qquad (5)$$

Differentiating this equation the constant c disappears. This allows to use the feedback diode (distortion is thus given only by the temperature dependency of the technological factor i_s). The transfer characteristic according the equation (4) is very flat for higher input voltages v_1, so the sensitivity is small. The sensitivity can be increased using the amplifier which multiplies the characteristic by the constant. To obtain more precise calculation of the altitude the equation (1) can be modified using Babinet formula to the form (6)

$$z(p) = \frac{T_o}{T_r}\left(1 - \left(\frac{p}{p_o}\right)^{\frac{T_r \cdot R}{Mg}}\right) \qquad (6)$$

where z(p) is the altitude, p is the air pressure, p_o=101.325 kPa is the sea level barometric pressure according the ISA, Tr=0.0065 K·m^{-1} is the temperature gradient according the ISA, R=8.3 J·K^{-1}mol^{-1} is the universal gas constant, M=0.02894 kg·mol^{-1} is the air molar mass, T_0=288.15 K is the temperature at the sea level according the ISA, g=9,81 m·s^{-2} is the gravitational constant. Software solution and microcontroller were used for the compensation of this no linearity.

3 HARDWARE DESIGN

The system consists of several blocks. The block diagram of the design system is depicted on the figure 1. [2]. The system consisted from a few parts (main parts, audio parts, altitude part, power supply, output indicators etc.). The analog differentiating network delivers the differentiation peaks at its output. The peaks are read off by the microprocessor. At the same time, the altitude above sea level is measured and its value applied for correction of the measured peak. The design must care for a quick and accurate measurement of the differentiation peaks. The parameters given in [4] were taken as the design basis.

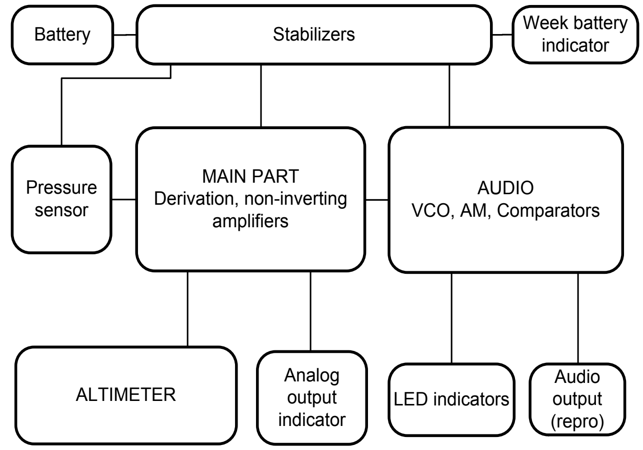

Figure 1: Block diagram of the realized system.

The main part derivates output sensor signal. The first stage is inverting voltage derivation part. Output voltage signal is processing in the non-inverting amplifier with high magnified. The circuits operated in the function of low-filter as well. The change of output voltage can be done change of sensitivity audio part. Output of IC3 (see fig. 2) controls VCO (voltage control oscillator) in audio part. IC4 (see figure 2) operates as non-inverting amplifier, one controls analog indicator.

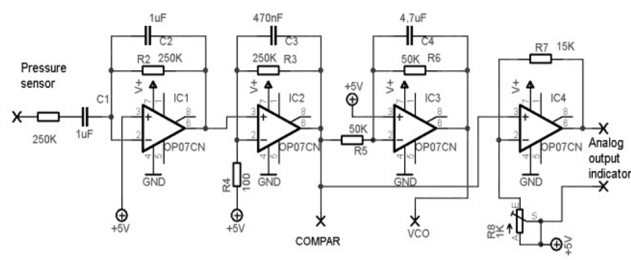

Figure 2: Circuit connection of the main part

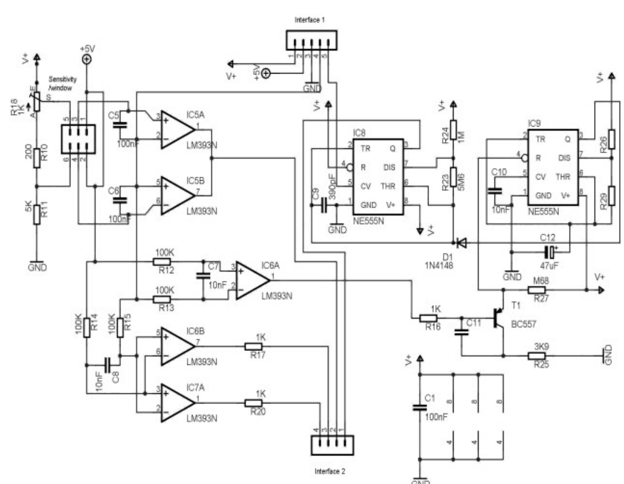

Figure 3: Circuit connection of the audio part

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Audio part is designed with comparators and timers. The comparator IC6a (see fig.3) is used for clear acoustic resolution between increasing and decreasing. Comparators IC6b and IC7a work with minimum window size. Ones serve for optical indication of increasing and decreasing only.

The simple altitude part indicates altitude to 1.5 km with very small error - figure 4. The output voltage signal from pressure sensor is connected to the input of IC14a (see fig.5). IC14a is non-inverting amplifier with magnification suitable for control of output indicator. Calibration is done by trimmer R36.

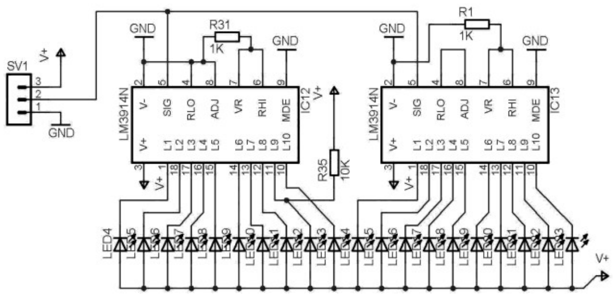

Figure 4: Circuit connection of the simple altitude indicator

The main part together with power supply part is depicted on the figure 5. The system is designed with supply voltage 9 V,

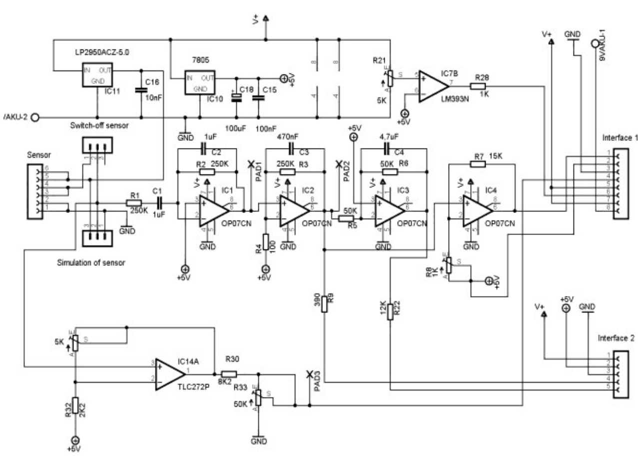

Figure 5: The main part with the power supply

The barometric system works with the MPX4115 pressure sensor, the principle is described in [1]. The data sheet gives the output voltage dependence for that type of pressure sensor as [5]

$$v_{out} = V_{cc}(c_1 p - c_2) \tag{7}$$

where V_{cc} is the supply voltage and p is the pressure, c_1=0.009 a c_2=0.095. By arrangement of the equation we can obtain the formula for pressure

$$p = \frac{\frac{v_{out}}{V_{cc}} + c_2}{c_1} \tag{8}$$

By setting the constants into (6) and arrangement we can obtain the formula

$$z(p) = \frac{T_o}{T_r}\left(1 - \left(\frac{p}{p_o}\right)^{\frac{T_r \cdot R}{Mg}}\right) = c_3\left(1 - \left(\frac{p}{p_o}\right)^{c_4}\right) \tag{9}$$

where the constant c_3=44330.8 and c_4=0.190261.

Derivation of the correction data. The values read for altitude are used for the differentiation peaks correction. Under the assumption of direct proportionality, the differentiating network output (the differentiation peaks value) can be written as

$$v_{peak} = c_5 \frac{dv_{out}}{dt} \tag{12}$$

where v_{peak} is the output voltage of the differentiating network and c_5 is a constant. The equation (7) applies for the pressure sensor output voltage, and (12) can then be arranged to the form

$$v_{peak} = c_6 \frac{dp}{dt} \tag{13}$$

where c_6 is a constant. The following formula applies to the vertical velocity

$$\frac{dz}{dt} = \frac{dz}{dp}\frac{dp}{dt} \tag{14}$$

where the dp/dt term cornensponds to the v_{peak} measured voltage value. To express the dz/dp term, we start with the equation (6), and differentiate it over pressure

$$\frac{dz}{dp} = c_7 p_o^{c_8} p^{-c_8} \tag{15}$$

where the values of the calculated constants after setting in are c_7=83.241276 and c_8=0.809739. By setting the converted pressure formula into (15) we get

$$\frac{dz}{dp} = c_7\left(1 - \frac{z}{c_3}\right)^{-c_9} \tag{16}$$

After setting of equation (6) into (14) we get the formula for the actual dependence of vertical velocity on the differentiation peaks and on the altitude as

$$\frac{dz}{dt} = \frac{v_{peak}}{c_6} c_7\left(1 - \frac{z}{c_3}\right)^{-c_9} \tag{17}$$

Marking one part of the formula (16) as a function F(z), we can use this function to generate a table with altitude values and values of the F(z) function as the corresponding corrections

$$F(z) = (1 - \frac{z}{c_3})^{-c_9} \quad (18)$$

The resulting formula for the real vertical velocity has the form

$$\frac{dz}{dt} = c_7 \frac{v_{peak}}{c_6} F(z) \quad (19)$$

where the F(z) values relating to the particular altitude are stored in the table.

4 CONCLUSIONS

The designed simple system is capable to measure a vertical velocity from 2 $m \cdot s^{-1}$, the altitude measurement is auxiliary information for the vertical velocity calculation, the measurement accuracy is 2 m. The system is necessary to calibrate, one also contains a calibration section. The system designed includes distortion compensation. The calibration of the designed system is performed by means of the SPICE program.

An electronic circuit was designed, taking care of the mathematical functions including compensation functions. The transient analysis of the electronic circuit connection was used for vertical velocity simulation.

The type MPX4115 pressure sensor was used in the system. Problem of nonlinearity due to the exponential function of barometric pressure versus altitude is discussed in detail. Using a linear interpolation, the altitude is calculated from the measured value.

5 ACKNOWLEDGEMENT

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