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Development of a fully functional standby backup glider variometer

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Abstract— Potential use of the piezoresistive technologies in the aviation industry reflects a huge attention in research and development in recent years. Requirements in the more/all-electric aircraft set new requirements and standards. Additional real challenges are the backup instruments that require independent power sources and sensors and of course a standby mode of operation. This paper presents a complete process of the development of a fully functional backup glider variometer as a final product. The device is developed to be simple, power efficient, highly accurate, configurable, and low priced. To complete all the above-mentioned advantages simultaneously, a method for a software optimization of digital sensors for vertical speed estimation is used. The system solution is based on Digital Signal Processing (DSP) algorithms discretized and adjusted for software implementation. Responsiveness, sensitivity, and algorithm performance are considered. The presented method in this paper is tested in real flight conditions on an Unmanned Aerial Vehicle (UAV) and piloted paraglider. Furthermore, additional research and tests are performed to implement a mechanical isolation of the sensor to achieve a real result as near as to the theoretical calculated performance. Finally engineering approaches are used for the designing of the electrical schematics, power consumption optimization and the electronic case design.

Keywords— altimeter, variometer, vertical speed, pressure, digital sensors, gliders

I. Introduction

Unpowered piloted sport and experimental aircraft usually are not under strict regulatory certification. In other words, they are not required to have standby backup navigation instruments. The unpowered aircrafts are performing day operations only and in most of the cases, they are performing Visual Flights. But if it is possible to have backup instrumentation that are not expensive, don't have special maintenance requirements, they are small and light enough and are power independent - for sure they are going to be almost mandatory for those flight. But not because of regulations, but because of their necessity - in-flight reference check, backup, or main instrument.

The widely introduced low powered piezo resistive sensors widely used in household and IT appliances could is used in this work in order to design and develop standby instrument that could be used in sport and experimental gliding aircrafts.

II. Backup altimeter requirements.

First, we need to state the main requirements of the backup altimeter:
-reliability;
-Low power consumption;
-Maintenance free;
-Light weight and volume;
-Accuracy.

Nowadays glass cockpit technologies are integrated in modern aircraft (including gliders and sport aircraft), digital electronic panels to employ a backup set of instruments are in the modern cockpits. But still the two main types are the pressure altimeter, or aneroid barometer, which approximates altitude above sea level by measuring atmospheric pressure, and the radio altimeter, which measures absolute altitude (distance above land or water) based on the time required for a radio wave signal to travel from an airplane. [1] Both types require specific Analog digital conversions, mechanical parts and special maintenance and periodic checks, Also sufficient power consumption is required.

Sensors with low power consumption, digital interfaces, miniature and light-weight packing, based on piezo-resistive technology such as Bosch Sensortec BME280, for example, are available at a low-cost price today and can be implemented in altimeter applications, replacing the stated in the previous paragraph. The benefits of piezo resistive technologies are:

- Low power consumption;
- Integrated ADC (Analog to Digital Converters);
- Low voltage requirements.

In the previous work of the author, such sensors are used in [3]. Based on those developments and additional research and design described in this paper an backup altimeter with a sound indication is developed.

The main technical requirements that the final device should cover:

- Ultra-low power consumption.
- Standardized small and worldwide commercial power supply (Single AA 1.5 V battery supply);
- Long life without battery replacement;
- Compact (volume and weight).

In this project as altimeter indication, a signal indication is going to be used. This is a common indication used to response rate of climb usually scaled to match typical glider rates of climb and descent. (+/-10 knots or +/- 5 meter/sec). Because of the different flight characteristics of gliders and different flight conditions indicated, the sensitivity of the variometer and sound volume should be adjustable. The sound indication directly represents the rate –higher tone frequency represents higher altitude rate.

III. ELECTRONIC LAYOUT AND DESIGN

A. Sensor module

A Bosh Sensortec BMP180/280 pressure sensor is used in this device. All competitive sensors could be used, but this is selected because of the integrated DCPU (Digital Signal Processing Unit) integrated in the sensor that could provide not only ADC but also some filter options. Integrating this unit in the sensor, unloading the MCU from additional calculations means direct decrease of the power consumption.

The dependence, which evaluates the vertical velocity, is derived from the barometric formula [2]:

$$p(z) = p_0 e^{\frac{-z}{z_0}} \qquad z_o = \frac{kT}{gm_0} \tag{1}$$

where p(z) is the pressure in altitude, p_0 is the sea level altitude air pressure, T is the temperature and the other elements in the equation are constants. The exponential element e^{-z} can be converted to the Taylor polynomial [2]:

$$\frac{dz}{dt} = -\frac{z_0}{p_0}\frac{dv(p)}{dt} \tag{2}$$

Based on [3], in this work a separate infinite impulse response filter (IIR) with a feedback filter coefficient of 4 is selected to be provided from the DCPU of the sensor.

B. Power module

As described in the introduction the power module is one of the most challenging mostly because a single pack of 1.5V AA size battery is going to be used. This voltage is appropriate for the sensor and the MCU to be powered, but not enough to produce appropriate sound volume indication. A charger pump TPS60303_DGS_10 by TI (Texas Instruments) provides stabilized power for the sensor and MCU. This configuration provides optimal power consumptions and keeps safe operational characteristics.

C. MCU(Microcontroller unit)

The TI MSP430G2452IPW14 was selected because of the low voltage operation mode and super low power consumption power modes. Additionally, it provides the exact number of input and outputs required:

- I2C interface;
- 2 DIO (digital Inputs/Outputs) required for the user buttons;
- 1 DIO required for the sound indication;
- All signals (TST, RST, P1.1) are only used for the programming and debugging connector.

D. Sound Indication module

To provide a loud sound it is required a charge pump to increase the voltage level of the selected sound frequency generated by PPM module of the MCU to the piezo sound beeper (driver). For a charge pump a NJU72501EQFN12 by JRC electronics is used. It provides three levels of amplifying the input signal.

Figure 1 visualize the PWM (pulse with modulation) of the signal generate to the piezo beeper:

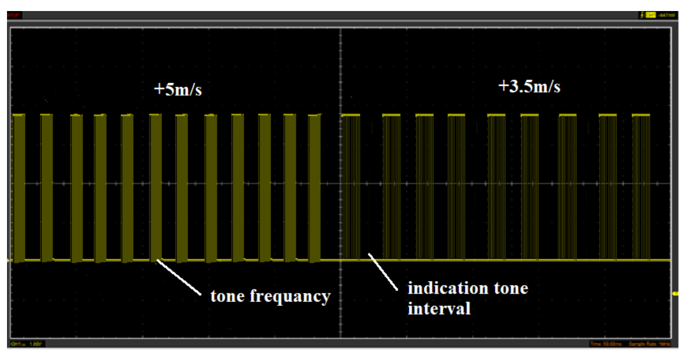

Figure 1. Sound PWM

E. User settings

User settings consist of setting the sound volume (tree level and additional silent mode) and sensitivity (10 level of positive rates and 3 level of negative rates including turn off the negative rate indication). The settings are stored in Segment C of the memory that is power independent and 10K Cycle of rewriting are guaranteed by TI.

F. Full Layout

The full assembly of the modules is designed followed by the technical specification and the datasheets. The schematic is shown on Figure 2 and the PCB (Printed Circuit Board) layout on Figure 3. It includes all necessary passive components

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providing the required stabilizing of the signals. The battery holder is mounted on the Board.

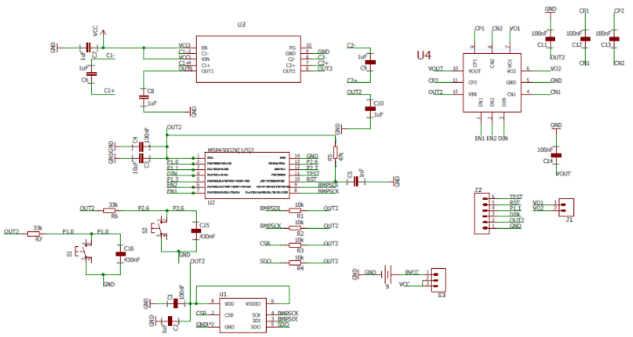

Figure 2. Schematics Layout

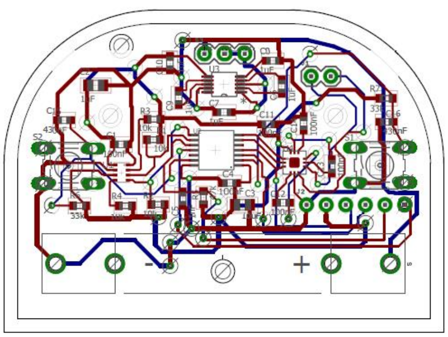

Figure 3.PCB Layout

IV. Software Development and Optimizations

The embedded software that controls the whole measurement process is accomplished the following tasks;

- Additional Butterworth filtering;
- Controlling user interrupts;
- Calculates the climb/descent rates;
- Generate PWM to the charge pump in order the appropriate sound to be executed ot the piezo driver;
- Control the power modes of the MCU and accomplished the most efficient power management solution.

On Figure 4 is shown the time diagram of the process over the current consumption snapshot.

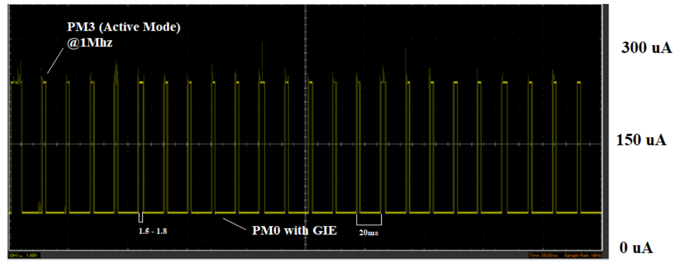

Figure 4.Current consumption and process execution

The sensor readings, Butterworth filter, altitude rate and PWM modulation calculation for the sound indication are executed and PM3 (Power Mode 3) at 1Mhz MCU clock frequency. This is repeated at 20ms (50Hz). In PM0 with the General Interrupt Mode and Pulse Modulation Module enabled.

V. Case Development

The case development expects holding all the hardware should provide a "pressure shield" of the pressure sensor. Initially a porous absorption material was used, but it increases the response rate of the sensor. Instead, a mechanical cover of the sensor is provided as shown on Figure 5.

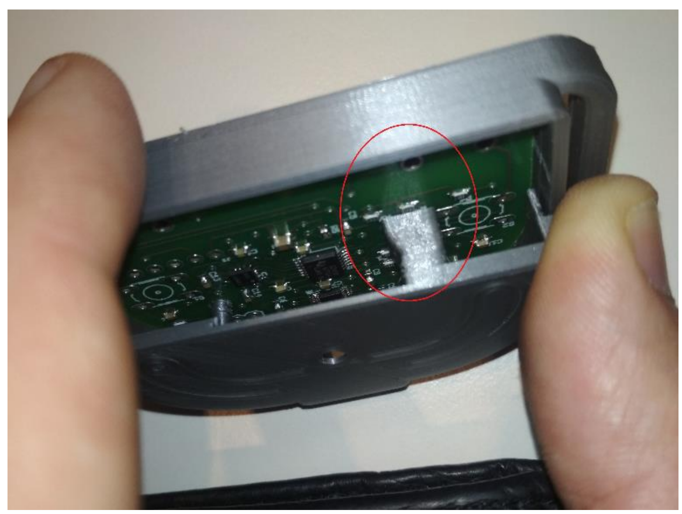

Figure 5. Sensor Mechanical Cover

On the next figures, the 3d model of the case is shown:

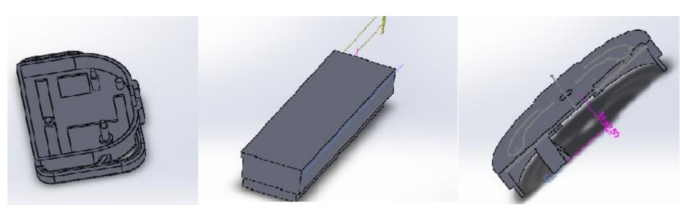

Figure 6. Case 3d models

VI. Conclusion

The result of designing a small backup altimeter is accomplished. Several test flights are performed and the device is fully functional and works as expected. The most advantage of using the piezo resistive sensor is the power consumption, the lower price and the high reliability. Unfortunately, the high relatability is not proved in all extrema conditions:

- Low temperatures (below 40 degrees Celsius);
- Freezing conditions;
- Water contamination.

However, all the above disadvantages could find their solution by additional heating of the sensor plate and producing a water shield.

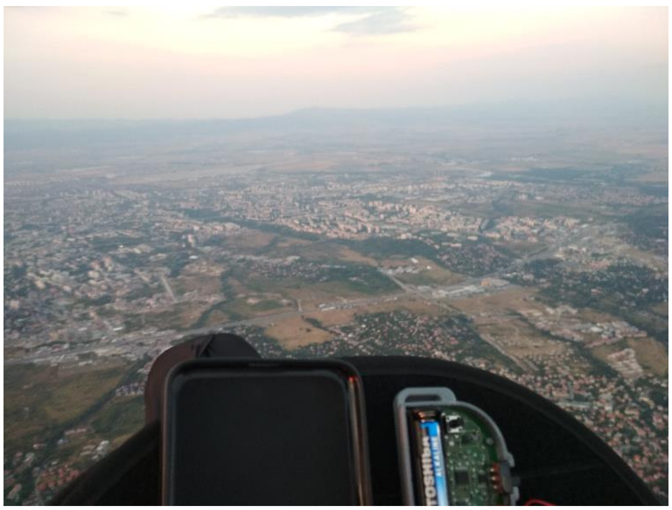

Figure 6. The variometer in flight

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