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Prototype of Wideband Air Sonar Based on STM32

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The paper presents a project of a low-cost prototype version of a wideband air sonar and the problems occurring during its development process. The aim of this work was to design a short range air sonar capable of creating the reflectivity map of its surroundings using an arbitrary shape wideband signal. The transmitting and receiving transducers that have been chosen for this application typically work in pulsed operation modes. Therefore, dedicated output and input circuits had to be designed to expand its capabilities without information losses. The signal generation, transmission, reception and storage are managed by a Discovery evaluation board with a STM32 microcontroller. The receiving data are saved on a SD card and are processed off-line.

Keywords: imaging air sonar; STM32; ultrasonic transducer.

1. Introduction

Basic assumptions of the designed system were determined by the variety of potential applications. The most popular imaging application of air sonar is the synthetic aperture sonar (SAS). The sensor moves along an assumed track (generally a straight line) and records the echoes from a scanned area. The special signal processing algorithms allow to transform those echoes into a reflectivity map and obtain the high resolution image of the terrain (Hansen, 2011; Kawalec, 2010). Another popular application is the Inverse Synthetic Aperture Sonar (ISAS). The stationary sensor records echoes from a moving object and dedicated algorithms allow to obtain image of the target. The principle of operation and preliminary results of such system are presented by Serafin *et al.* (2017). The air sonar can also detect small object in the limited space. In this case the size of the object is defined by its reflectivity, which defines the level of its echo in the received signal. The best example is drones, which usually present a weak acoustic echo. Another potential application is employment of the air sonar as the navigational sensor for mobile robots. The detection of obstacles helps them to navigate around the room.

To use the air sonar in the above described imaging applications the system had to be portable. This means that it had to have as small as possible package dimensions and it had to be battery powered. The imaging applications require wide signal bandwidth allowing to reach better image quality in terms of the range resolution. The assumed signal has the carrier frequency of 50 kHz and the bandwidth of at least 10 kHz. In this frequency range the device shouldn't cause any signal distortion.

2. System design

Sonar systems just like the radar systems contain transmitting and receiving channels, control unit and processing unit (Richards, 2005). The functional block diagram of the sonar is presented in Fig. 1. The lines represent the power paths and the bold ones the signal paths. Accordingly to the assumptions, the whole system is supplied by a small 12 V Li-Pol battery.

As the control unit an STM32F4 microcontroller was applied. To reduce the cost of the system and to avoid the necessity of designing the hardware required

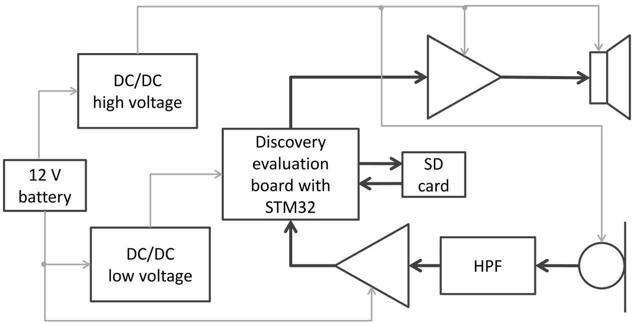

Fig. 1. The functional block diagram of the designed air sonar system.

for the processor's work, an STM evaluation "Discovery" kit with an expansion board including SD card socket was used. The raw received data are stored in the external memory and the processing operations are performed off-line in a PC application.

The ultrasonic sensor series 600 Instrument Grade Transducer by SensComp (Polaroid) was chosen. It has the flat receiving and transmitting characteristics in the considered frequency band. It is an electrostatic sensor and it requires high operating voltage ranges with the maximum value of 400 V and the bias voltage between 150 V and 200 V. According to its datasheet, in its nominal application, it can reach the maximum range of the level of 15 m and the resolution of 3 mm, if an appropriate driver is used.

The use of STM32 and SensComp series 600 transducers in prototype system is not a new idea. Holocomb *et al.* (2015) used these components to design the wideband ultrasonic recording system. In their solution it was unnecessary to transmit the signal, therefore the transmitting channel was not present there.

2.1. *Transmitting channel*

The Sample Electronics (n.d.) company proposes the standard design of the transmitting and receiving circuits for the SensComp series 600 sensor. They assume the use of a transformer to obtain required voltage ranges. The simulations proved that it is appropriate only for the short pulse signals, as shown in Fig. 2.

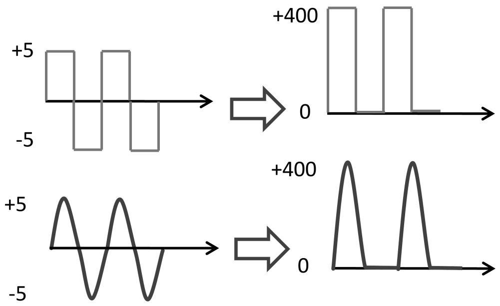

Fig. 2. The signal passage through the transmitting path proposed by Samples.

The signal is transformed in the way that only positive voltage appears on the output. If the signal has a shape that is different from bipolar square, the shape distortion occurs and part of information is lost. Thus, another solution should be found.

To meet the transducer voltage range requirements, the signal from the digital-to-analog converter have to be amplified by the linear operating amplifier. To preserve the signal dynamic range the slew rate should be at least 30 V/µs. It also should have flat or linear frequency characteristic. These conditions are met by the Apex Microtechnology PA88, whose typical application is a piezoelectric driver.

The disadvantage of such solution was the necessity of using a stable, high voltage supply for the amplifier. A capacitor charger controller LT3751 was applied. The controlling elements were adjusted to ensure transformation of the battery voltage to the levels of 400 V.

To verify the correctness of the design, LFM pulses with the duration of 1 ms and the bandwidth between 45 and 55 kHz were used. The generated sounding pulse is fed to transmitting transducers, and emitted as an ultrasonic acoustic wave. The assumed waveform and recorded signal at the end of transmitting channel are presented in Fig. 3.

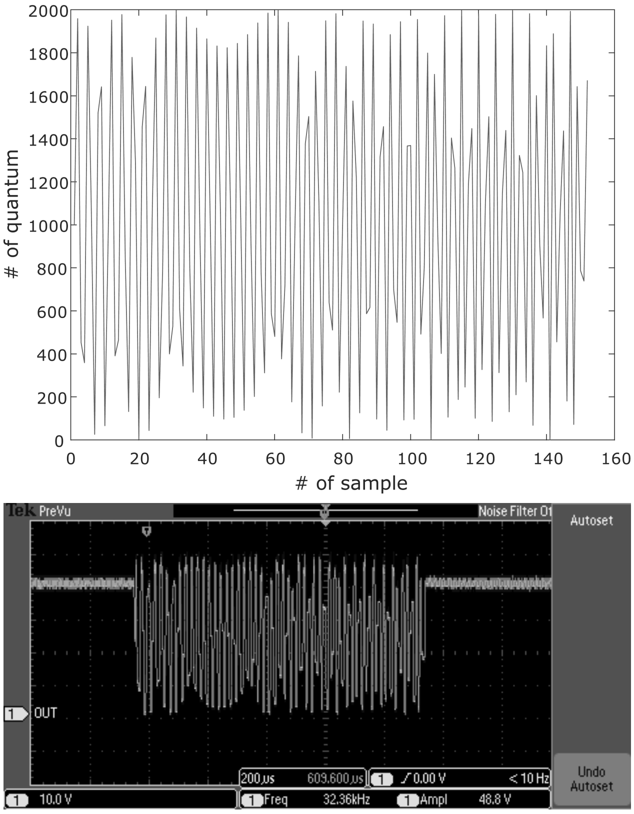

Fig. 3. The generated signal and its amplified version at the end of transmitting path.

As one can see, the given waveform corresponds to the output signal with no visible distortion. It proves that the designed transmitting channel works properly. Also the required 150 V bias voltage is clearly seen.

2.2. Receiving channel

The ultrasonic echoes reflected from an observed object are received by another transducer and converted into voltage changes. The main goal of the receiving channel is to transform signal from sensor to the voltage range of the STM32 analog to digital converter (ADC) input, namely 0–3 V. This function is realized by the circuit presented in Fig. 4.

Three main parts of the receiving channel may be distinguished. The first one is the RC high pass filter that removes the bias voltage. The next part is a summing amplifier, which adds a small constant component to the signal. Its value is set by the ratio of R41 and R42 resistances. Except of its main function the linear operational amplifier U2, due to its frequency bandwidth, also acts as a low pass filter with a cut-off frequency around 100 kHz. The preprocessed signal is amplified to the required voltage ranges by the amplifier U3. The presented order of signal transformations allows to keep unipolar power supply for every module.

To verify the correctness of the receive channel design a simple experiment was made. The sonar sensors were placed in front of each other at the distance of 70 cm and the transmitted signal was directly received and measured by the receive channel. Such arrangement ensures the highest incoming signal intensity. The result of the experiment is presented in the oscillogram (amplitude vs time) in Fig. 5.

The received signal is clearly seen in the oscillogram, however there is also an interference from the transmitting channel. The "leakage" signal has a higher amplitude than the received signal. The source of the interference is probably signal propagation trough the ground path. This interference is of course an unwanted element, but can be used to synchronize the successive echo records and it can be further deleted in postprocessing software. In further system development process this phenomenon will be removed.

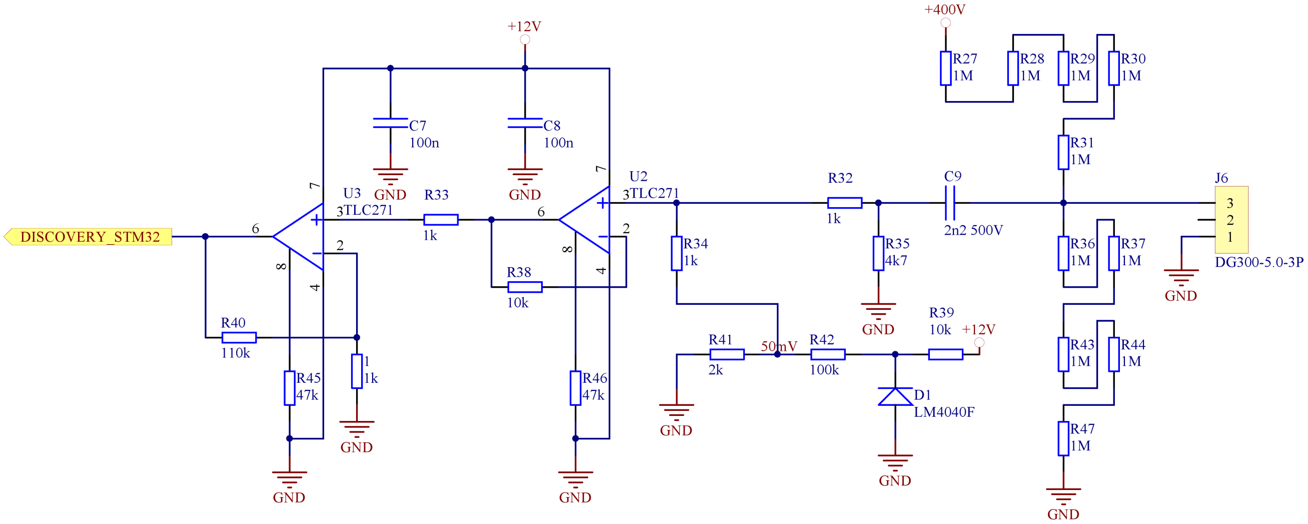

Fig. 4. The scheme of receiving channel.

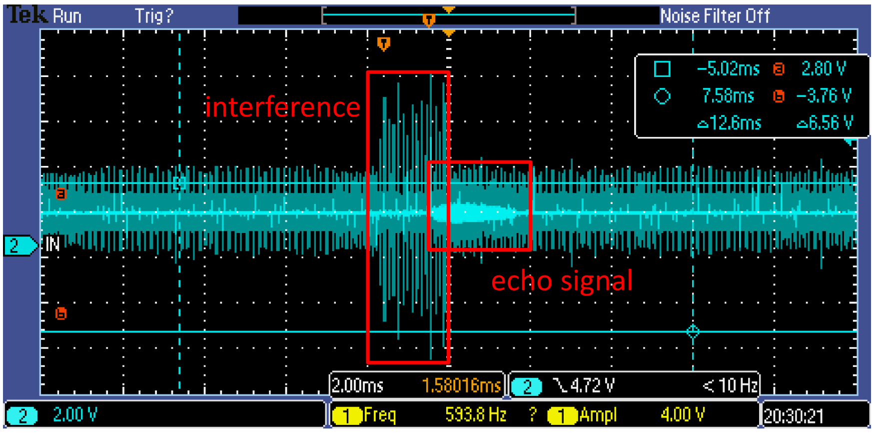

Fig. 5. The amplitude of signal vs time at the end of receiving channel.

3. Results

The prototype of the designed sonar has been tested with objects having strong reflectivity, i.e. the trihedral cones with square reflecting areas. The designed device and the testing scenario are presented in Fig. 6.

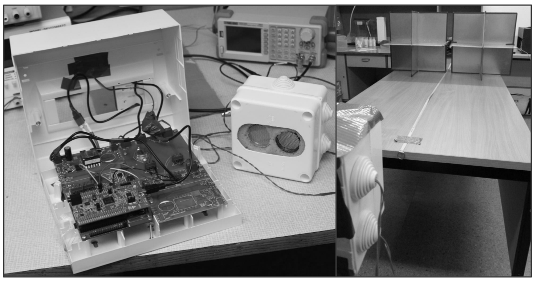

Fig. 6. The prototype device and testing scenario.

The first test was set to examine the correctness of the signal storage on the SD memory card. Figure 7 shows the result of the experiment, the stored signals represent the received ones with high fidelity. The occurring DC offset is associated with the ADC input voltage ranges 0–3 V.

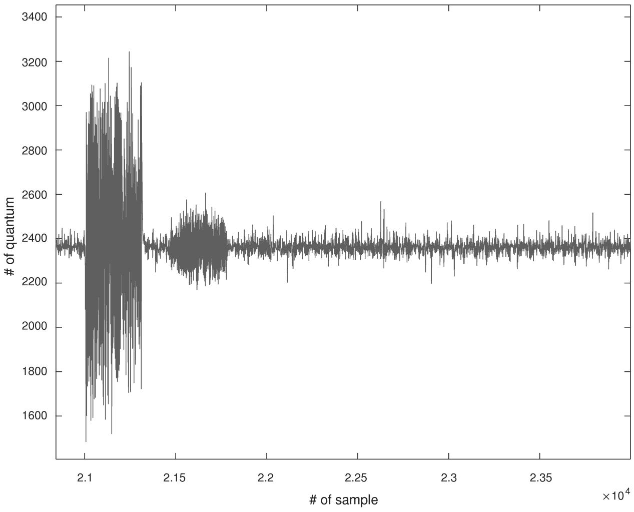

Fig. 7. Signal reflected from the reflecting cone.

The next important parameter, from the point of view of potential applications, is the air sonar range resolution. Its theoretical value can be estimated by the following expression (Richards, 2005):

$$d_R = \frac{v}{2B}, \tag{1}$$

where v is the acoustic wave propagation velocity and B is the transmitted signal bandwidth. In our case the range resolution should be at the level of 1.7 cm. To verify this value, two reflecting cones were placed in front of sonar sensors. Their mutual distance was changed between 0 cm and 5 cm by every 1 cm. The reflected echo signals were stored and subsequently they were range compressed. The last distance, at which the reflectors' echoes were distinguishable was designated as the range resolution of the air sonar. Figure 8 presents echoes from objects recorded in two successive scans. It proves that the receiving results are repeatable and any differences between them are associated with noise. It also can be seen, that the distance about 2 cm ensures the echoes separation. The results allow to state that the practical resolution of the air sonar is consistent with its theoretical value.

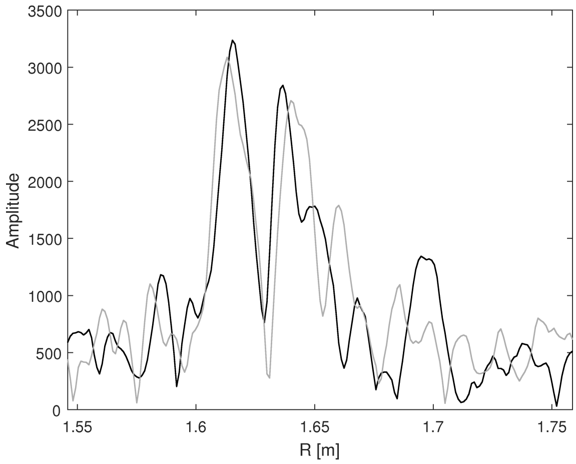

Fig. 8. Echoes from two objects separated by 2 cm recorded in two successive scans.

A similar scenario was used to verify the sonar range. The reflecting cone was moved away from the transducer and the level of the recorded echo signal was examined. The distance, at which the object become invisible in signal, was designated as the sonar range. The reflecting cones that were used have the reflecting area of 0.25 m^2 and the air sonar range for them is around 5 m. For the imaging and scanning purposes that the air sonar was designed for this is enough.

As previously underlined, one of the project assumptions was the low cost of designed sonar. Including the price of the elements and so-called development cost, the total amount didn't exceed 200 €. It is a quite reasonable price for a prototype of such device.

4. Summary

The design of the wideband air sonar with the STM32 microcontroller as a control unit was presented in the paper. The main design assumption on the price, bandwidth, resolution and range of the system was met. Further work will concern the improvement of signal purity. Especially the receiving channel requires further work to extend the voltage ranges and to narrow the effective filtering band only to the frequencies of the transmitted signal. Also the use of operational amplifiers with wider frequency band. Despite the advisable further development of the device, the prepared air sonar is useful in the research work on signal processing.

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