POVEĆANJE TOLERANCIJE GREŠKE ADC AD7799

INCREASING FAULT TOLERANCE OF ADC AD7799

Artem BASKO[1], Elena PONOMARYOVA[*2]
[1] Department of Automation and Computer-Integrated Technologies,
Prydniprovska State Academy of Civil Engineering and Architecture, Ukraine
[2] Department of Computer Science, Information Technology and Applied Mathematics,
Prydniprovska State Academy of Civil Engineering and Architecture, Ukraine

Pri dizajniranju bilo kojeg automatskog sistema upravljanja procesima, za mnoge industrije nemoguće je isključiti upotrebu analogno-digitalnih pretvarača. Standardni 5V logički nivoi CMOS-a i TTL-a postupno se smanjuju na 3.3V logičke nivoe LVTTL-a, a zatim na 2.5V i 1.8V logičke nivoe CMOS-a, kako bi se povećala brzina integriranih kola. U skladu s tim, zahtevi za takvim pokazateljima kao što su tačnost, brzina, greške u kvantizaciji i u većini slučajeva tolerancija grešaka u procesu pretvaranja signala su sve veći. Cilj rada je primeniti i u praksi rešiti dvosmislenost ADC signala tokom prenosa podataka s ADC-a na mikrokontroler kako bi se prilagodio stabilnom načinu rada, predlaže se korišćenje niskopropusnog filtra na bazi RC sklopa u digitalnom delu kola. Sastavljen je ispitni sto, a pomoću modelirajućeg okruženja MATLAB Simulink testiran je LPF filter. Pravi eksperiment na ispitnom stolu je takođe izveden. To pokazuje da je primena niskopropusnog RC filtra u digitalnom delu električnog kola efikasna metoda. Ovde je takođe opisano kako odabrati RC filter.

Ključne reči: *stabilizacija signala, analogno-digitalni pretvarač, filtriranje signala, dinamičko merenje težine, automatizacija*

Designing any automated or automatic process control system, for many industries, it is impossible to exclude the use of analog-to-digital converters. The standard 5V logical levels of CMOS and TTL gradually decrease to 3.3V of the logical level of LVTTL, and then to 2.5V and 1.8V of logical levels of CMOS, to increase the speed of the integrated circuits. In accordance with this, the requirements for such indicators as accuracy, speed, quantization errors and, in most cases, fault tolerance in the process of signal conversion are increasing. The aim of the work is to apply on practice solve the ambiguity of the ADC signal during data transmission from the ADC to the microcontroller in order to tune to a stable mode of operation, it is proposed to use a low-pass filter based on the RC circuit to the digital part of the circuit. A test bench was assembled and using the MATLAB Simulink modelling environment, the LPF Filter was tested. The real experiment on test bench was made. That shows that the implementation of a low-pass RC filter to the digital part of the electrical circuit is an effective method. Here is also describes how to select an RC filter.

Key words: *signal stabilization, analog-to-digital converter, signal filtering, dynamic weight measurement, automation.*

1 Introduction

Nowadays, no one of the automation systems can be designed without using an analog-to-digital converter (ADC). Typically, control systems use an ADC with a resolution of 8 bits, 10 bits, 12 bits, 16 bits and rarely 24 bits, to convert an analog signal from various sensors. This provides the conversion of the analog signal to digital for the convenience of further signal processing.

In common, research works to improve signal stability is aimed at improving the signal of the analog part of the ADC and filtering the data already received from the ADC.

For example, an 8-bit pipelined ADC using preprocessing to divide the input signal range into sub-intervals and amplify the residual signal for further processing in the subsequent steps [1]. Or pipelined successive-approximation-register (SAR) ADC. That ADC shows very high resolution and

[*] Corresponding author, email: pricmech@ukr.net

even with low level of noise reducing, it also shows good energy efficiency and a high sampling rate [2-4].

Two-stage pipeline ADC architecture with a large first-stage resolution, enabled with the help of a SAR-based sub-ADC. Such kind of ADC achieves low-power, high-resolution and high-speed operation without calibration [5-6].

In that articles were discussed, the basics of analog low-pass filtering, frequency transformations for transforming analog low-pass filter into band-pass, band-stop, or high-pass analog filters are considered. Main applications for low-pass filters are channel-separation, A/D antialiasing and general signal processing [7-9].

Also, Sallen-Key active low pass filters based on passive components RC are used for many years, there are described applying it with active components such as amplifiers and passive components, low-pass SC filters based on the continuous-time version of the Sallen-Key low pass filter [10-11].

Moreover, there are a lot of studies of data filtering and processing. They are described a particular measurement situation, how best to reduce the noise while retaining as much of the signal as possible is important [12-16].

Decreasing of logic levels of microcircuits bring to the problem of signal instability arises while data transmitting from the ADC to the microcontroller. Furthermore, investigating ways to improve the stability of microcircuits, this research contributes to a further increasing of stability at even lower logical levels.

2 Analyze of the problem

In the practical application of microcircuits for various circuitry solutions, the problem of unstable operation often arises. Usually, engineers change a suitable chip to a more stable one, instead of improving the work of a suitable one.

This work presents an applied solution to the problem that occurs when transmitting data from the ADC to the microcontroller via the SPI interface.

Since the main issue is related to the instability of the signal during the data transfer between ADC and microcontroller, then let's look at an example of how to transfer data from the primary converter to the microcontroller. The channel of data transmitting is shown on Fig.1.

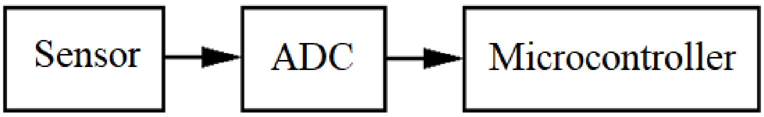

Fig. 1. The channel of transmitting data

The following communication channel is used in many automated or automatic control systems to obtain data from sensors of temperature, pressure, weight, speed, acceleration, etc. The problem of signal instability during transmission between the ADC and microcontroller. To solve such problem proposes method of signal filtering based on low-pass RC filter. It is simple and useful approach for such kind task.

To test the proposed method, a test bench was constructed. It is a scale for static weighing. An electrical schematic diagram of the test bench is shown in Fig.2.

As the primary transducer we will use the HBM PW6DC3 strain gauge weight sensor, it converts mechanical deformation of the body into an electrical signal.

The STM32 microcontroller, series F103C8T6, based on the ARM Cortex-M3 processor, was selected as the data collection, processing and control system.

According to the ADC problem encountered, AD7799-based ADC was used, it is a 24-bit sigma-delta ADC with low-noise instrumental amplifier and programmable gain. AD7799 uses the SPI interface, a sequential, full duplex synchronous data standard designed to provide simple and inexpensive high-speed connectivity to microcontrollers and peripherals. When the test bench was made and put it into operation, we will see the instability of data transmission. Instability of work is manifested in the noising of data transmission using SPI interface.

Looking for ways to solve this problem, it turned out that the AD 7799 ADC instability does occur not in a single case. Since there is a problem with this ADC, some engineers are usually used a hardware reboot mode to solve that problem at that time when the system crashes and data in not arrived.

But this is not a complete solution to the problem because it takes some time to restart, which means that digital data filtering algorithms cannot be used.

Initially, the circuit was investigated without a RC low-pass filter R7 and C22 which are shown in the electrical circuit of Fig.2.

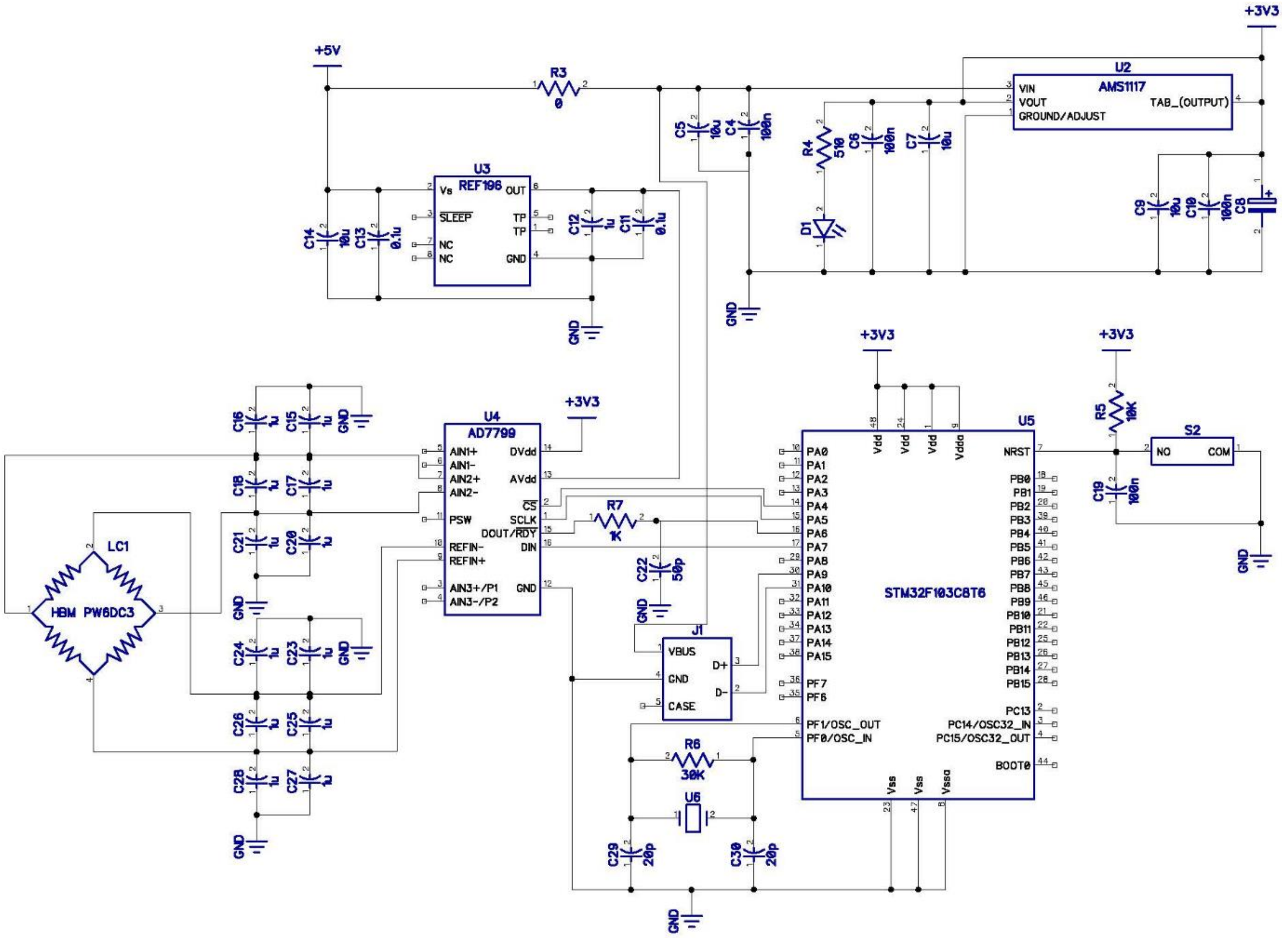

Fig. 2. Electrical schematic diagram of the test bench

An oscilloscope was used to investigate the forms of signals flowing during data exchange. The oscilloscope's probe was installed on the DOUT ADC, the diagram Fig. 3 is shown that the whole parcel is 32 bits. The first 8 bits duplicate the command that was submitted to the input DIN of the ADC from the microcontroller, it indicates from which ADC channel to receive data and what is the data request. Since the resolution of the ADC is 24 bits, the next 24 bits have an informative structure

Consider the upper form of the signal without the use of capacitor C22 and resistor R7, the Fig. 4 are showed the oscillations of the distorted data.

But it was clear that when studying the signal with the oscilloscope's probe, the ADC has begun work with more stability and the noise amplitude is in average 300 mV. It means without the oscilloscope's probe it will be more of a negative impact on data transmission and noise amplitude will be higher than 300 mV. So, we know that the capacity of the oscilloscope probe is about 15 pF and they are not enough to stabilize the data signal.

The ADC was launched at different update rates from 4.17 to 470 Hz, changing the FS0, FS1, FS2, FS3 registers of ADC AD7799. When the ADC update frequency changes, the microcircuit also works unstable, but at a lower frequency the time increases, but the operation failure is inevitable. The diagram of the dependence of the update rate on time to fault is shown in Fig.5.

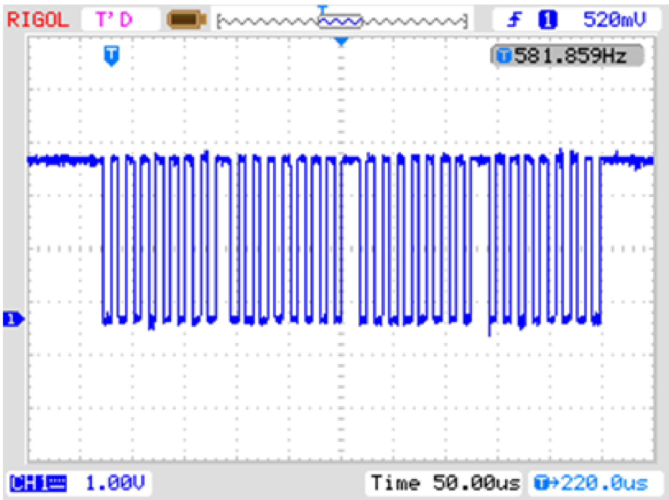

Fig. 3. Parcel from ADC on the pin DOUT ADC

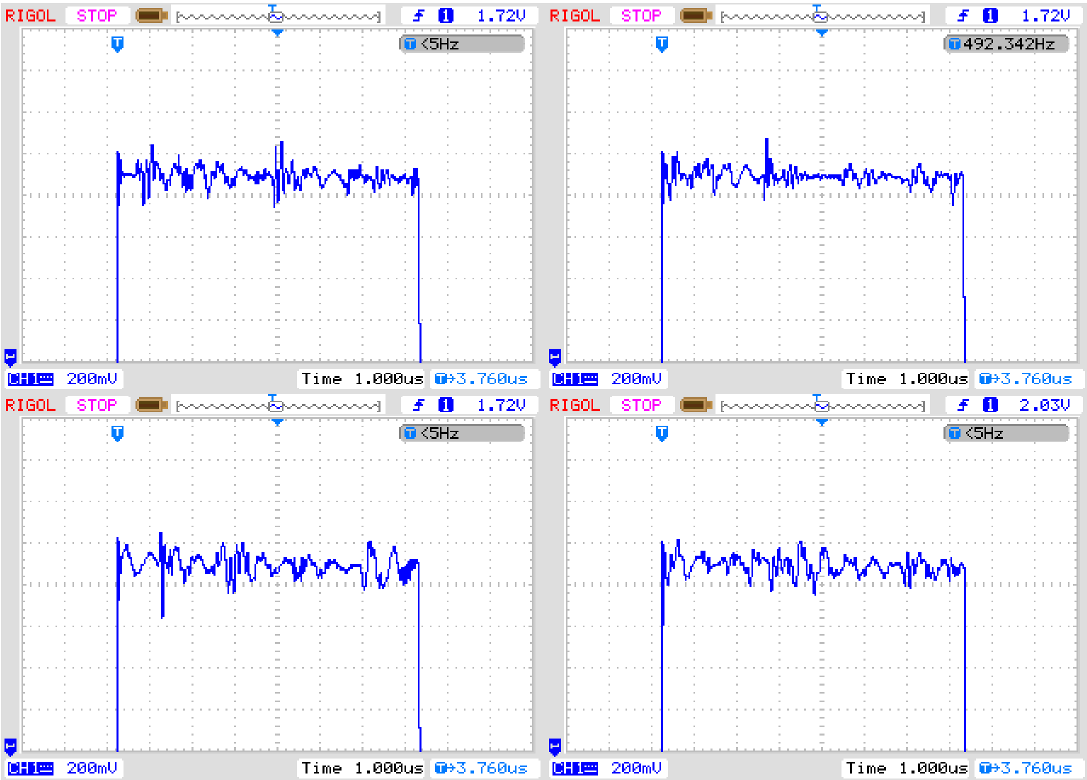

Fig. 4. Data signal without the use of a RC filter

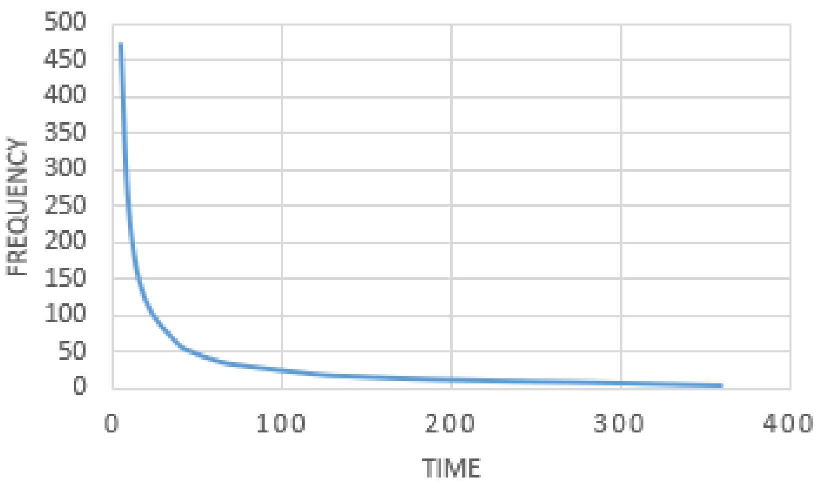

Fig. 5. Dependence of the update rate on time to fault

3 Modelling and testing of the proposed method

To stabilize the signal, it is necessary to select the correct combination of R and C electrical elements. In the general case, the output voltage of such an RC circuit is described by equation (1):

$$U_{out}(t) = U_{in}(t) + C \cdot e^{-\frac{t}{R \cdot C}} \quad (1)$$

Based on the theory of automatic control, this RC circuit is an aperiodic link (inertial link, aperiodic link of the first order). The following link is described by the differential equation (2):

$$T\frac{dy(t)}{dt} + y(t) = K \cdot x(t) \quad (2)$$

From theory of automation low pass continuous-time filter can also be described in terms of the Laplace transform. Their impulse response, in a way that lets all characteristics of the filter be easily analyzed. The low-pass filter of first-order can be described in Laplace notation as (3):

$$W(p) = \frac{K}{Tp+1} \quad (3)$$

In the equation of the transfer function (3), K is the gain, $T = R \cdot C$ is the time constant.

Earlier data were obtained using an oscilloscope in the wfm format, they were exported to the MATLAB environment for analysis and design. Using the MATLAB Simulink modeling environment, three models with different value of T were build, it is showed in Fig.6.

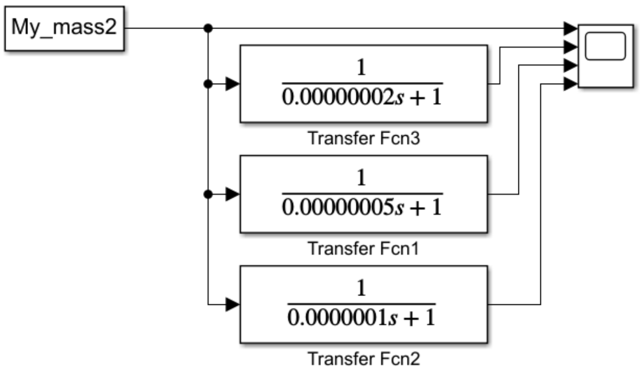

Fig. 6. Transfer function with different time constants T

Based on the data obtained in Fig.7, the graph 2 has more faster the slew rate than the graph 3, but has less stable signal.

The graph 4 has less faster the slew rate than graph 3, but has more stable signal. So, graph 3 has an optimal ratio of the slew rate to the reference voltage and a sufficiently stable signal.

For complex comparison RC filter must be implemented into test board and get new data signal. To rebuild existed board the nominals of R and C must be known. Resistor R7 is equal 1000 Ohm it is enough for flowing current between microcircuits. To calculate nominal of capacitor C22, need to use next an equation:

$$C = \frac{T}{R} = \frac{0.05 \cdot 10^{-6}}{1000} = 50 \cdot 10^{-12}\ \text{F} = 50\ \text{pF}$$

Know the R and C we can also find the Pass Band, so the frequency range of cut-off point f_C is calculated by equation (4):

$$f_C = \frac{1}{2 \cdot \pi \cdot R \cdot C} \quad (4)$$

Using the equation (4) the cutoff frequency equals:

$$f_C = \frac{1}{2 \cdot 3.14 \cdot 1000 \cdot 50 \cdot 10^{-12}} = 3.18 \cdot 10^6 \text{ Hz}$$

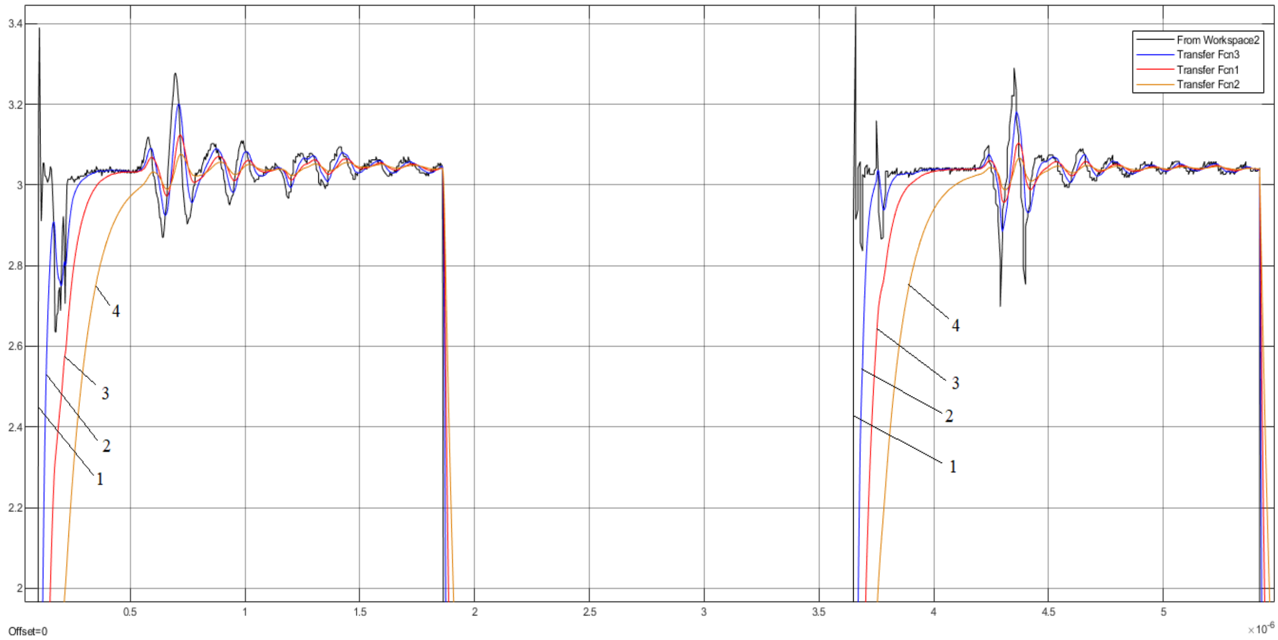

Fig. 7. Plots of transfer functions: 1 - original data from oscilloscope,
2 - transfer function with $T = 2 \cdot 10^{-8}$, *3 - transfer function with* $T = 5 \cdot 10^{-8}$,
4 - transfer function with $T = 1 \cdot 10^{-7}$

Comparing the obtained Fig.8 using the RC filter and Fig.6 without it, we can conclude that the filter with the task of stabilizing the digital signal works quite well, and the signal became clearer, and the ADC stop disappeared, and therefore we can say that the implementation of the RC LPF filter is an effective solution.

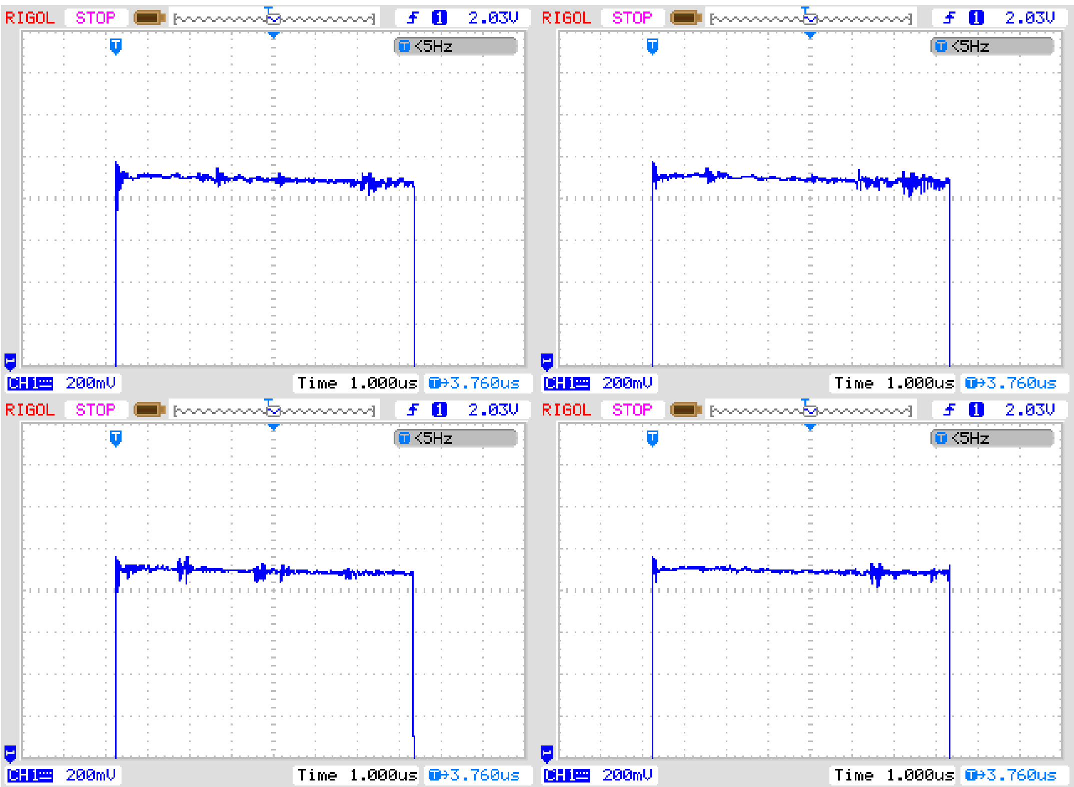

Fig. 8. RC is used for filter data signal

4 Conclusion

Complexity of devices are Increasing, so the volume and speed of information transfer between devices are exchanged has increased extremely. To improve performance digital part of ADC the known ways of solving this problem were analyzed and the own schematic solution of the problem was presented. The test bench was assembled and an experiment was conducted there is also was made computer modelling of LPF in MATLAB Simulink, using this approach amount of noise was reduced and stabilized the ADC.

Moreover, the proposed data filtering method can be applied not only to this AD7799 ADC model, but also to others will all depend on the frequency of data transmit, resistor nominal and the capacitor rating. The results presented can be used in radio engineering to design modern automatic and automated control systems of varying degrees of complexity.

The results of the study are planned to be used for the design of complex dynamic weighing systems, checkweighers in order to ensure high accuracy and quality of data during measurements.

5 References

[1] **Brarua, A., M. Tausiff,** Code width built-in self-test circuit for 8-bit pipelined ADC, IEEE, (2011), pp. 287-291.

[2] **Oh, S., K. Kim, H. Chae,** Bandpass ΔΣ ADC using pipelined SAR ADC, Electronics Letters, 56 (2020), 10, 480.

[3] **Sarma, V., B.D. Sahoo,** Pipelined ADC based design of bandpass Delta Sigma-ADC, Electronics Letters, 49 (2013), 10, pp. 646-648.

[4] **O'Hare, D., A. Scanlan, E. Thompson, B. Mullane,** Bandwidth Enhancement to Continuous-Time Input Pipeline ADCs, IEEE Transactions on Very Large Scale Integration, 26 (2017), 2, pp. 404-415.

[5] **Lee, C., M.P. Flynn,** A SAR-assisted two-stage pipeline ADC, IEEE Journal of Solid-State Circuits, 46 (2011), 4, pp. 859-869.

[6] **Fan, H., Y. Liu, Q. Feng,** A Reliable Bubble Sorting Calibration Method for SAR ADC, AEU-International Journal of Electronics and Communications, 122 (2020), p. 153.

[7] **Thompson, M.,** Intuitive Analog Circuit Design, Newnes, New York, USA, 2014.

[8] **Rao, K.,** Signals and Systems, Birkhauser, Cham, Switzerland, 2018.

[9] **Molnar, G., M. Vucic,** Bernoulli Low-Pass Filters, Circuits and Systems II: Express Briefs, 9 (2014), 5, pp. 1-5.

[10] **Soltan, A., A. Radwan, A.M. Soliman,** Fractional Order Sallen–Key and KHN Filters: Stability and Poles Allocation, Circuits Systems and Signal Processing, 34 (2014), 5, pp. 1461-1480.

[11] **Serra, H., N. Paulino,** Design of Switched-Capacitor Filter Circuits using Low Gain Amplifiers, Springer, Cham, Switzerland, 2015.

[12] **Suresh, R.D.,** Signals and Systems in Biomedical Engineering, Springer, Boston, Canada, 2013.

[13] **Miura, G.,** Noise reduction, Nature Chemical Biology, 16 (2020), 2, p.106.

[14] **Chen, W.,** The Regularized Low Pass Filter, Journal of Signal and Information Processing. 5 (2014). 1. pp. 14-16.

[15] **Yu, F., J. Lu,** Symmetry in digital signal processing, Nanjing Li Gong Daxue Xuebao/Journal of Nanjing University of Science and Technology, 42 (2018), 5, pp. 615-621.

[16] **Sengupta, S.,** Handbook for Digital Signal Processing Technometrics, Technometrics, 34 (2012), 4, p. 430.