Methods of Forming the Control Voltage in the Current Generation Problem for Electrical Impedance Tomography

Shcherbakov I. D., Katsupeev A. A., Shcherbakova M. V., Tjaglicova P. V.

Abstract: ***The paper considers questions of control signal for injection current generation in electric impedance tomography devices. The most common injection current generation scheme is voltage controlled current sources. In these circuits, the shape, frequency and amplitude of the current are set by the control voltage. The most common control voltage generation schemes are considered; their advantages and disadvantages are indicated. A circuit using direct digital synthesis and an amplitude-tuning digital-to-analog converter was selected, its block diagram was developed, and an operation algorithm was described. The developed scheme will improve the efficiency of the research by the method of electrical impedance tomography due to the complete automation of the process of controlling its parameters.***

Keywords: ***electrical impedance tomography, current source, voltage generator, hardware structure.***

I. INTRODUCTION

Electrical impedance tomography (*EIT*) [1] - medical imaging method based on electrical measurements on the surface of the biological object *BO* with high-frequency electric current I_c injecting that allowing to reconstruct conduction field Ω or its variation ΔΩ inside *BO*. The research process using the *EIT* method in the general case consists of a number of operations:

- N electrodes E_n ($n \in 1$ .. N) are attached to the object of study along the perimeter of the *BO*;
- the formation of the injected current signal I_c;
- supply of current I_c to certain electrodes in accordance with the *IS* injection strategy with the number of combinations N_{inj};
- registration in accordance with the measurement strategy *MS* with the number of combinations N_m of the potential difference $\Delta\varphi_i$ ($i \in 1..L$, где $L = N_{inj} \cdot N_m$);
- reconstruction of the conductivity field Ω or its change ΔΩ inside the *BO* based on the information $\Delta\Phi=\{\Delta\varphi_i\}$, a priori information on the *BO* (electrode location, shape of the external boundary, preliminary distribution of the conductivity Ω, etc), information about the shape, frequency and current amplitude I_c, injection strategy *IS* and measurement *MS* ;
- visualization of reconstruction results.

As shown in [2-4], the metrological characteristics of the entire device for *EIT* depend on the stability of the characteristics of the current source, because ΔΦ measurement results are a response to the injection of current I_c into *BO*. Taking into account the fact that the impedance Z of *BO* has a complex nonlinear dependence of the frequency f_c of the injected current I_c [5], we can conclude that the most important task in designing a current source is to ensure the accuracy of installation of not only its output amplitude A_c, but also f_c. In addition, an additional requirement for the current source is the ability to digitally set A_c and f_c in a given range [6].

The most widely used in the construction of *EIT* devices were voltage and source controlled by voltage [4]. Such circuits include a voltage generator and a voltage-current converter. Information on the shape, amplitude A_c and frequency f_c of voltage U_c is supplied to the generator input. The voltage U_c is supplied to the input of the voltage-current converter, at the output of which a current I_c is generated , the shape and frequency of which are equal to the shape and frequency of the voltage U_c, and the amplitude is directly proportional to A_c.

Therefore, the first step in building *IT* is to develop a stable controlled voltage generator U_c.

II. METHODOLOGY

There are several approaches to the construction of control voltage generators U_c in the problems of *EIT*. Traditional one involves the use of analog circuits using frequency-setting *RC* chains [7,8]. The block diagram of the generator is shown in Figure 1.

As can be seen from the presented diagram, the main advantage of mentioned control voltage generator is its ease of implementation, which requires a minimum of components. The algorithm of functioning of described current source is reduced to rotating knobs of the *RC* filter and A_c setting circuit variable resistors until the required values are monitored by appropriate devices (for example, an oscilloscope) will be reached.

At the same time, the above scheme has a number of obvious disadvantages:

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- the operation of the device with an *RC* generator involves the manual installation of A_c and f_c parameters by changing the values of the elements of the *RC* filter in feedback. Without control equipment, manual setting of these values manually can be difficult and cause delays in preparation for the research;
- high demands are placed on the temperature stability of *RC* filter components, as a result of a change in their characteristics, stability f_c may be impaired.

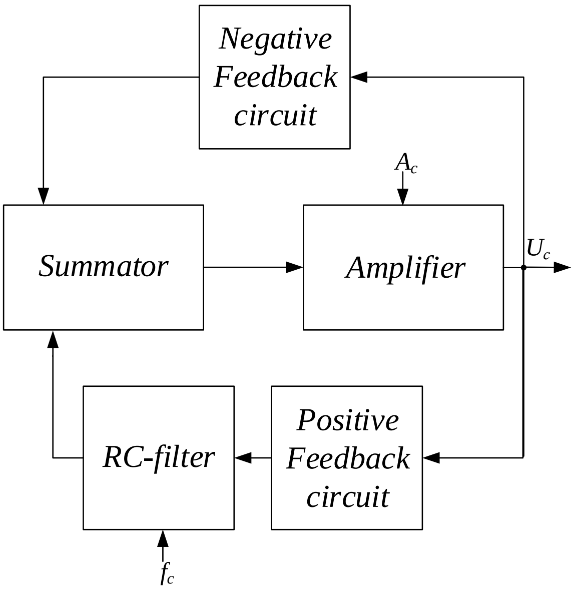

Fig. 1.The structural diagram of the RC generator

There is a known scheme in which the formation of U_c with is performed using a digital-to-analog converter (*DAC*), the structural diagram of such a generator is shown in Figure 2. In this case, the microcontroller *MK* receives from the personal computer *PC* data on the shape, frequency f_c and amplitude A_c of the current I_c. Based on the given shape, the *MK* selects from the read-only memory *ROM* the numerical codes of the signal values for the period for a given frequency f_c (Figure 3).

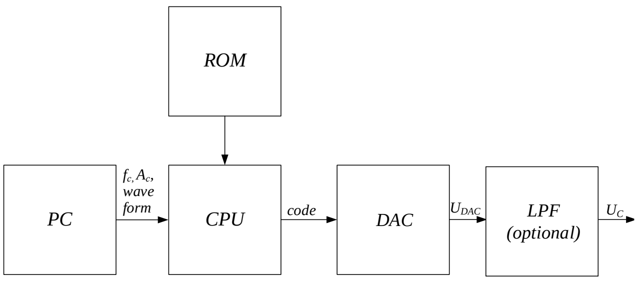

Fig. 2.The structural diagram of the *DAC*-based generator

The selected codes are scaled to a given value of the amplitude A_c of the current Ic and are cyclically output to the *DAC*. The process of outputting codes continues until the *MK* receives a signal to stop the injection process. Optionally, a low-pass filter can be installed at the output of the *DAC*, which will smooth the transitions between the levels of discretized values of U_c at the output of the *DAC*. However, in this case, it is possible to use only a sinusoidal waveform. The advantages of this construction principle include the high stability of A_c and f_c and the simplicity of their task using the *MK* used in the circuit. In addition, using the above scheme, the formation of an arbitrary waveform is possible. Moreover, the values of the points from which one period U_c is built are stored in additional memory, which is a drawback of the above scheme: the values of points for all f_c must be loaded into the indicated memory device. In addition, adding additional device modes can be quite time consuming. The accuracy of the task A_c and f_c in this case is determined by the bit depth *n* of *DAC* and its sampling frequency f_{DAC}. The maximum frequency f_c is limited not only by the speed of the *DAC*, but also by the speed of the *MK*.

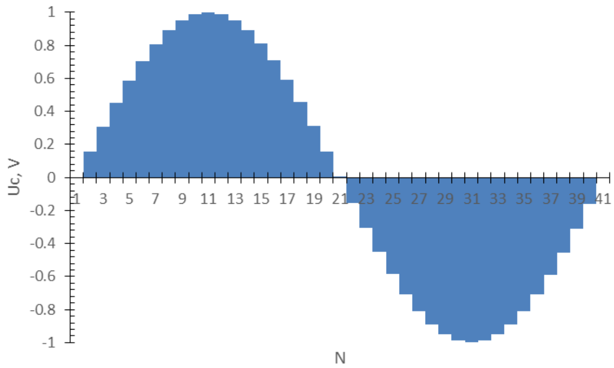

Fig. 3.Discretized in time and amplitude representation of U_c

An alternative solution is to use specialized direct digital synthesis (*DDS*) solutions, in which a specialized microcircuit is used [9], in the memory of which an array of values of signal period points is already recorded, and f_c is changed using the built-in clock divider. A_c is set using a separate *DAC*. The developed block diagram of a described generator is shown in Figure 4.

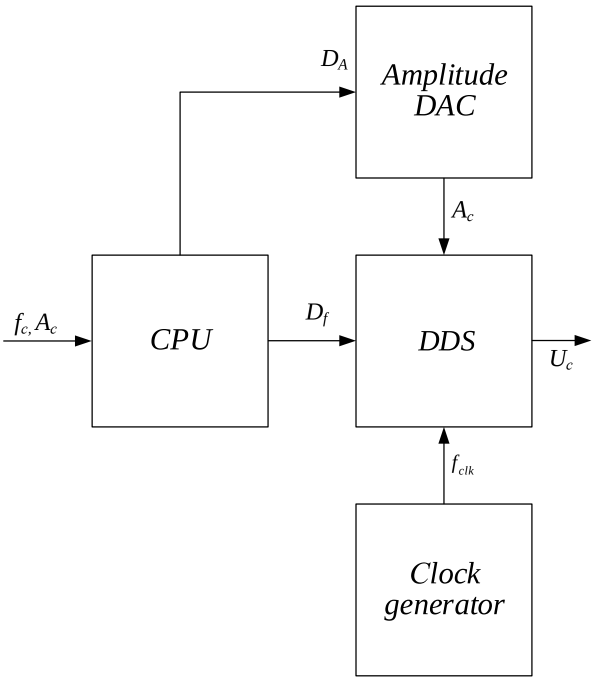

Fig. 4.Block diagram of unit forming U_c using *DDS*

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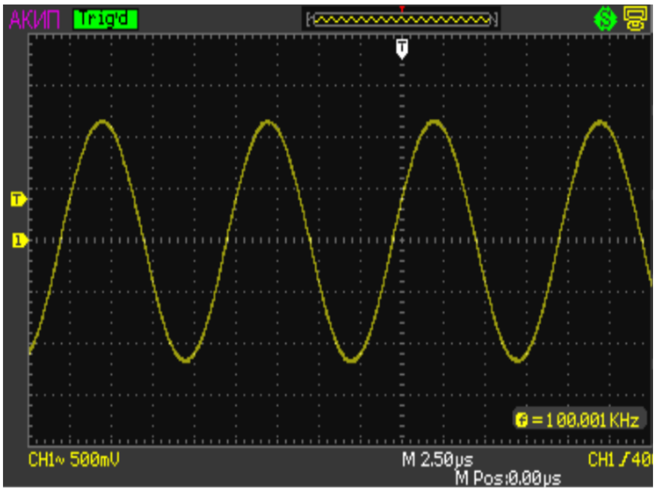
The disadvantages of the described approach include the complexity of the hardware implementation and the need to use additional components. At the same time, the above scheme has several advantages in the form of high stability A_c and f_c and the simplicity of their task and control. The accuracy of the A_c setting is determined by the bit width *n of* the amplitude *DAC*:

$$A_c = V_{ref} \cdot \frac{D}{2^n},$$

where V_{ref} is the reference voltage *DAC*, *D is a* given digital code corresponding to A_c .
Similarly, for *DDS*, the accuracy of setting f_c is also determined by the bit width *n* of the built-in frequency divider:

$$f_c = f_{clk} \cdot \frac{D}{2^n},$$

where f_{clk} is the clock frequency.
During the measurement cycle, there is no need to continuously send data from the *MK* to the actuators (amplitude *DAC* and *DDS*), as well as there is no need to store bulk arrays of the generated signal U_c points. The amplitude *DAC* must have a high bit capacity *n* for more accurate tuning of A_c, however, there are no special requirements for its speed.
Thus, despite the disadvantages of this scheme in the form of a higher complexity of its implementation, the advantages in the form of stability, accuracy and simplicity of setting A_c and f_c, unloaded *MK* allow to provide effective automated control of research parameters by the *EIT* method.
The authors assembled a test bench using the *DDS AD*9834, *AD*5621 amplitude-*DAC* and *CPU STM*3 2F411*RET*. *DDS AD*9834 is controlled by the *CPU* via the *SPI* interface and allows you to generate a sinusoidal, rectangular and triangular waveform with a frequency of up to 37.5MHz. *DAC AD*5621 is controlled by the *CPU* through the interface *SPI*, *MK STM*32*F*411*RET* floor differs from PC value f_c and A_c and waveform. Thereafter, control signals are formed for the *DAC AD*5621 and *DDS AD*9834. An example of the results of the generator for a sinusoidal signal is presented in Figure 5.



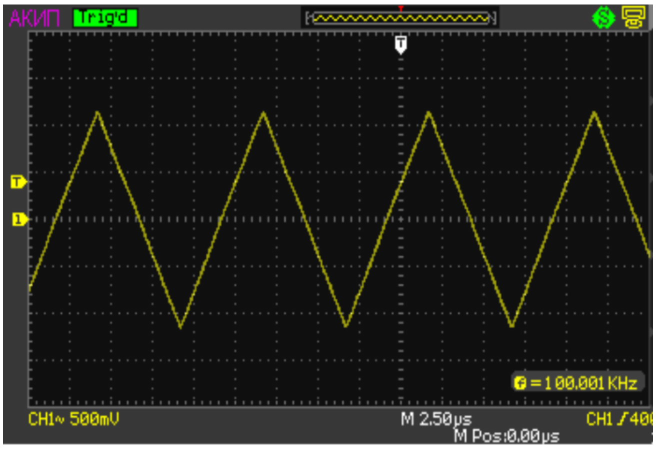


Fig. 5.Example of the results of the generator

III. RESULT AND DISCUSSION

The role of a current source in an electric impedance tomography device is considered. It is shown that one of the most important parts of the most common voltage controlled current source is the control voltage generator, which determines the shape, frequency f_c and amplitude A_c of current I_c.
The article discusses the principles of constructing some schemes for constructing control voltage generators (namely, an *RC*-generator using a digital-to-analog converter (*DAC*), direct digital synthesis (*DDS*)), identifies their advantages and disadvantages. A comparative analysis of the considered schemes is presented in table 1. As can be seen from the table, *DDS* and *DAC* outperform *RC*-generators, but *DDS* has less load on the *CPU*.

Table- I: A comparative analysis of the considered schemes

Parameter	Type of voltage generator		
	RC	***DAC***	***DDS***
Digital control	-	+	+
Stability	-	+	+
Accuracy	-	+	+
CPU load	*no*	*high*	*low*
The complexity of the implementation of the voltage of a triangular and rectangular shape	*high*	*low*	*low*
Element Base Requirements	*high*	*middle*	*middle*

Based on the analysis, a control signal generating circuit was selected for generating the injected current I_c using *DDS* and amplitude *DAC*, its block diagram was developed, and its operation algorithm was described. The developed scheme will improve the efficiency of the research by the method of electrical impedance tomography due to the complete automation of the process of controlling its parameters. The authors present an example of the results of the *DDS AD*9834 generator controlled by the *STM*32*F*411*RET CPU* and amplitude-tuning *DAC AD*5621.

IV. CONCLUSION

The role of a current source in an electrical impedance tomography device is considered. It is shown that one of the most important parts of the most common current sources is the control voltage generator, which determines the shape, frequency f_c and amplitude A_c of current I_c. A comparative analysis of the considered schemes shows that control voltage generators based on *DDS* is more efficient solution that will improve the quality of the electrical impedance tomography method research.

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