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_inj, 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 ∈ {1 .. N}) are attached to the object of study along the perimeter of the BO;
- the formation of the injected current signal I_inj;
- supply of current I_inj to certain electrodes in accordance with the IS injection strategy with the number of combinations N \_ij;
- registration in accordance with the measurement strategy MS with the number of combinations N_m of the potential difference Δψ, (∀i ∈ I, ∀e \in E = N \_ij \setminus N_m);
- reconstruction of the conductivity field Ω or its change ΔΩ inside the BO based on the information ΔΦ={Δψ}, 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_inj, 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 and measurement results are a response to the injection of current I_inj into BO. Taking into account the fact that the impedance Z of BO has a complex nonlinear dependence of the frequency f, of the injected current I_inj [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_inj, but also f. In addition, an additional requirement for the current source is the ability to digitally set A_inj and f 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_inj and frequency f of voltage U_inj is supplied to the generator input. The voltage U_inj is supplied to the input of the voltage-current converter, at the output of which a current I_inj is generated, the shape and frequency of which are equal to the shape and frequency of the voltage U_inj, and the amplitude is directly proportional to A_inj. Therefore, the first step in building IT is to develop a stable controlled voltage generator U_inj.

II. METHODOLOGY

There are several approaches to the construction of control voltage generators U_inj 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_inj 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:
- 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.

The advantages of this construction principle include the high 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.

The selected codes are scaled to a given value of the amplitude $A_c$ of the current $I_c$ 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.

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

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
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 $U_I$ 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 AD9834, AD5621 amplitude-DAC and CPU STM32F411RET. DDS AD9834 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 AD5621 is controlled by the CPU through the interface SPI, MK STM32F411RET floor differs from PC value $f_c$ and $A_c$ and waveform. Thereafter, control signals are formed for the DAC AD5621 and DDS AD9834. 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-1: A comparative analysis of the considered schemes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type of voltage generator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RC</td>
</tr>
<tr>
<td>Digital control</td>
<td>-</td>
</tr>
<tr>
<td>Stability</td>
<td>-</td>
</tr>
<tr>
<td>Accuracy</td>
<td>-</td>
</tr>
<tr>
<td>CPU load</td>
<td>no</td>
</tr>
<tr>
<td>The complexity of the implementation of the voltage of a triangular and rectangular shape</td>
<td>high</td>
</tr>
<tr>
<td>Element Base Requirements</td>
<td>high</td>
</tr>
</tbody>
</table>

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 AD9834 generator controlled by the STM32F411RET CPU and amplitude-tuning DAC AD5621.
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 $f$, and amplitude $A_i$ of current $I_i$. 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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