Issues of developing receiving equipment for the passive method of induced polarization

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Abstract. The article deals with the design of receiving equipment for the passive method of induced polarization (IP). It is shown that the best option for recording this kind of signals is a circuit with an input analogue part and amplification of 50-100 times, as well as an input gain of at least 3 MΩ and a digital part based on a modern twenty-four-bit analogue-to-digital converter (ADC). In this case, it is preferable to use one ADC per channel without multiplexing, for better suppression of inter-channel interference. Signal processing is performed using modern microcontrollers based on the Cortex M4 core, and then the data is transmitted via Bluetooth to a laptop or tablet, where visualization and post-processing is carried out. Thus, the proposed scheme for the implementation of the receiving equipment meets all the requirements for the receiving equipment for the passive IP method, and can be introduced into the practice of field work.

1. Introduction
To date, the development of receiving equipment for the passive method of induced polarization is very important, since in scientific periodicals everything comes down to single works, which, on the one hand, is due to the not so widespread use of this method, on the other, the design specifics receiving equipment. An analysis of modern sources by the method of induced polarization shows that today an active version of the design is mainly developing, namely, various options for electro tomography and other options. For example, in [1], the authors cite the results of observations of electrical resistivity and analysis of aquifers in Laos using a multi-electrode setup (56 electrodes). The authors indicate that they used advanced methods (IMEE and SuperSting R8 / IP) for recording conductivity in 2D mode, as well as 3 profiles for recording induced polarization. The results obtained are in good agreement with the exploration drilling data. Analysis of this work shows that the depth of effective exploration, both for conductivity and for induced polarization, does not exceed 70-80 meters. As the practice of field observations [2-3] shows, the maximum depth does not exceed 100 meters, which greatly restricts the use of methods and this equipment for exploration of deeper deposits of ore anomalies, but allows one to evaluate the structure of the upper part of the geo-section.

The authors of [4] provide observational data and analysis of data on the effect of temperature and other parameters to determine the properties of the host environment, including to determine the boundaries of permafrost. In another work [3], the authors point to the possibility of determining the characteristics of clay and clay-containing material in the depths using spectral induced polarization. The basis of this method is the measurement of complex conductivity in the frequency range 1 kHz - 1 MHz. The paper presents sets of conductivity data values for different types of clay, as well as values
of induced polarization. Thus, the authors of [5] analysed the typical characteristics of clay formations in the medium, which will allow in the future, when carrying out field work, to more accurately interpret the anomalies in the measurement results. For example, in near-surface electrical prospecting, the authors of [6] propose to use the method of an artificial neural network (ANN). The authors point out that the use of this method allows to speed up the calculation, and also gives a higher accuracy when estimating the parameters of the Cole-Cole model. The use of pre-trained neural networks for evaluating both the parameters of the Cole-Cole model and for interpreting the data obtained is a promising direction in electrical exploration, since it will allow not only solving the detection problem, but also, to some extent, solving the identification problem, and in the future with the accumulation of a sufficient number of training samples, then evaluate the depth and structure of the assumed ore anomalies.

Estimation of the depth of occurrence of ore anomalies is also possible using downhole resistivity and induced polarization methods. In a later work [7], the authors analyze the application of the methods of induced polarization and resistivity, the authors provide data on modelling the apparent resistivity and apparent polarizability at different depths of immersion of the source in the well. The authors point out that the position of the source in the borehole and the position of the assumed anomaly have a significant impact on the results of measurements on the daytime surface of the Earth. In [8], the authors estimate the observed voltage of induced polarization on the Earth’s surface depending on the depth of immersion of the sphere; based on the simulation results, the authors indicate that registration in this case is possible up to depths of about 300 m and to a greater extent depends on the ratio of the depth of immersion of the sphere, distance spheres from the well and the depth of its immersion.

The induced polarization of various host rocks, such as sand, granite, smectite, etc. very often depends on the presence of such disseminated minerals as graphite, pyrite, magnetite, etc., the authors of [9] analysed the influence of shape, composition, size, and others, characteristics of electrically conductive inclusions on the parameters of induced polarization. In this work, in the course of physical modelling, it is shown that the magnitude of the induced polarization effect for these media directly depended on the normal component of the electric current density on their surface, and the relaxation time directly depended on the total active surface area of the inclusions. The analysis of this work shows the possibility of using the obtained data in the interpretation of field measurements, both when using electro tomography and for various kinds of passive methods of electrical prospecting.

In [10], the authors point out that the use of the induced polarization method in the frequency domain has its limitations, namely, it comes down to the need for a sufficiently large number of observations at a point, therefore, the time domain is usually used in field work. Thus, the use of modern methods of electro tomography has become widespread, which is confirmed by the works considered above and in other works [11-14]. For example, in [11], the authors provide data on the use of electrophotography to search for gold-bearing alluvium deposits.

2. Methods and materials

Analysis of modern measuring equipment for electrical exploration shows that today there are two different approaches to the design of this equipment. In the first case, when measuring at multichannel electro tomography stations, multichannel ADCs with a multiplexer or specialized ADCs for each channel are used. For the two-channel measuring layout considered in the article, some design issues of this kind of equipment have already been considered [15,16]. In the general case, the measuring part of the receiving equipment model can be divided into two parts: analogue and digital.

Analysis of modern sources has shown that today the most optimal solution is to use various types of low-noise differential amplifiers with an input impedance of more than 3MΩ and a gain of about 50-100 per stage, followed by a bandpass of 0.1-100 Hz and a band-stop filtration.

In general, the development of receiving equipment for the passive method of induced polarization with the ability to estimate the depth of occurrence of ore anomalies has a number of features, which are due to the fact that it is necessary to register fluctuations of 1 μV or less. To implement such indicators, it is advisable to use input analogue amplifiers with a resistance of the order of 3MΩ, since the apparent soil resistance can vary widely depending on moisture saturation. An additional requirement is that the
minimum linear and nonlinear distortions in the channels, or rather, the distortions in the input channels, should have a minimum discrepancy between the channels, since this will affect the resulting value of the induced polarization parameter, and they will give a constant value of the IP parameter even in the absence of any kind anomalies. Considering that the value of the recorded signals is \( \mu \text{V} \) and hundreds of nV, then the best solution in this case would be the use of precision differential amplifiers, which allow suppressing synchronous noise by 120 dB in voltage, and also have a large input impedance of about 10 M\( \Omega \) or more, and provide amplification 50-100 per cascade. In earlier works, various versions of the analogue path have already been given [15-16]; in this paper, it is proposed to use a single-stage circuit to amplify the received signals, which provides amplification and matching of the input impedances. Signal filtering is carried out using the digital part of the receiving equipment. As an amplifier, it is proposed to use the well-proven INA128 amplifier manufactured by Texas Instruments, which has a gain drift of 50 ppm / °C, noise in the 0.1 - 10 Hz frequency band - 140 nVPP and an input impedance of 100 G\( \Omega \).

The digital part of the receiving equipment is reduced to converting signals into digital form, filtering, and post-processing of signals. The best option for a frequency range of 0.1 - 100 Hz is to use a 24-bit sigma-delta ADC (AD7768, AD7714YRZ, MAX11200EEE +, etc.). For example, the AD7768, at a sampling rate of 1 kHz, and a reference voltage of 1.8 V, provides 21-22 effective digits, which, even without taking into account the input gain circuits, will record signals with a level of the order of 500 nV. ADCs of this kind transmit information via a parallel bus to a microcontroller, and are controlled by sending commands via a serial SPI or UART bus. The use of such an implementation scheme makes it possible to simplify both the implementation of the circuit topology and to minimize design errors.

Digital processing of the received signals is carried out on an ARM architecture microcontroller, in this case the most optimal in terms of price-quality ratio and entry threshold is STM32 microcontrollers, on the basis of which digital filtering of signals is carried out and then signals are transmitted to a personal computer, where further mathematical signal processing takes place and their visualization. A mandatory requirement for a microcontroller is the presence of an arithmetic coprocessor that provides floating point calculations for digital filtering of signals, as well as the ability to receive data via a parallel interface with a frequency of about 1 MHz, microcontrollers with a core no worse than Cortex-M4 comply with this requirement. To organize digital filtering using a filter with a finite impulse response and suppression in the attenuation band not lower than 60 dB. To provide such characteristics, a filter of the order of 200-300 links is required, which, together with other calculations on signal processing, will require about 512 KB of RAM. Considering all of the above, the minimum clock frequency of the microcontroller required for its correct operation is 32 MHz, and the clock frequency of the periphery is not lower than 1 MHz. The software part of the microcontroller device is implemented in the C language.

Further processing of the received data is carried out using a portable tablet based on the Android or Windows operating system, which, using a wireless data protocol based on Bluetooth technology, exchanges information with the measuring part of the receiving equipment. Next, the measured signals, calculation results, and the parameters of the measurement itself are saved in the device's Flash memory.

3. Results
In the course of analysing the modern element base, the most optimal twenty-four-bit ADC is the AD7768, which provides both a multichannel mode of operation, up to 8 channels per device and provides 60 dB of inter-channel interference suppression. The STM32WB55 series, which has 100 pins, a built-in Bluetooth radio module, as well as a mathematical coprocessor and a maximum clock frequency of 64 MHz, satisfies as the optimal microcontroller with all the characteristics. Figure 1 shows a block diagram of the implementation of such an implementation of the receiving equipment for the method of induced polarization.
Thus, the proposed block diagram of the receiving equipment meets all the requirements of modern equipment when working by the IP method and can be used to design the receiving equipment. This circuit allows to receive signals with a voltage of the order of hundreds of nV, and the lower threshold of sensitivity is limited only by the intrinsic noise of the input amplifier.

4. Conclusions
Thus, in the course of the study, a diagram of the implementation of receiving equipment for the passive method of induced polarization was considered. A block diagram of the implementation is given, which, using a modern element base based on INA128 differential amplifiers, a twenty-four-bit AD7768 ADC and a series of STM32WB55 microcontrollers, will also allow field measurements using Bluetooth wireless technology, which in turn will reduce the influence of the human factor on the measurement result.

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