FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ ústav teoretické a experimentální elektrotechniky

Switch card for measurements in electrical impedance tomography

Martin Balajka, Jan Mikulka, Jan Dušek (BUT)

Electrical Impedance Tomography (EIT) is a non-destructive method for analyzing the homogeneity of the electrical impedance inside the analyzed object by measuring the voltage potentials on its surface. The principle is to feed the object with a harmonic current and measure the voltage on the measuring electrodes, followed by solving the inverse problem of conductivity reconstruction. Compared to other tomographic methods, its advantages can be found mainly in the lower financial requirements for implementation, the absence of ionizing radiation, etc. It can be encountered in biomedicine, material engineering, geophysical mapping or, for example, in the monitoring of chemical processes. In biomedicine, EIT can be encountered, for example, in static and dynamic reconstruction of tissues, analysis of tumors, blood clots, breathing and many others [1-2]. In materials engineering, EIT is mainly used as a technique of non-destructive diagnostics [3]. In the chemical industry, we can encounter EIT when determining the homogeneity of emulsions [4]. In geotechnical engineering, EIT plays an important role in predicting and monitoring the condition of water dams or other structures [5]. All applications across fields have a common goal, which is very accurate measurement of voltage potentials, accurate generation of excitation current, accurate and fast digitization of measured quantities and high-quality reconstruction of the conductivity of the monitored object. For the design of techniques that can be applied in practice, the tomograph designed by us, which enables research of related methods on a small laboratory scale, is therefore of great importance.

SOCIAL RELEVANCE

The switching card for measurements in electrical impedance tomography (EIT) is a completely new device developed at the Institute of Theoretical and Experimental Electrical Engineering in the laboratory of electrical impedance tomography, which consists of academic staff and students of the Faculty of Electrical Engineering and Communication Technologies, Brno University of Technology. The motivation for the development of the device was the lack of commercially available devices to support research at the EIT. In the last five years of development, only 3 systems can be found that can be used in the research of EIT methods, the characteristics of which are summarized in tab. 1. By comparing the individual systems, it can be concluded that the system proposed by us has an indisputable advantage in the variable and unlimited number of electrodes, the frequency range together with the resolution of the measuring transducers, see the technical description. In addition, the Open IET system [6] has a proprietary electrode system formed on foil joints intended only for measurements in the supplied container. Portable EIT and SWEIT systems were published in [7], respectively. in [8], but are not commercially available.

Table 1: Currently available systems to support EIT methods research.

Name	Number of electrodes	Excitation current	Frequency range	Measuring convertor resolution	Year of introduction	Reference
Open EIT	32	unspecified	80 Hz – 75 kHz	16 bits	2018	[6]
Portable EIT	16	0.1 mA	0 – 100 kHz	unspecified	2018	[7]
SWEIT	16	0.1 mA – 10 mA	1 kHz – 1.1 MHz	unspecified	2020	[8]

This lack of commercially available devices simultaneously forces a number of research groups to work with synthetic data generated in computer software (Matlab, etc.), see e.g. [9], [10]. The results of published works are then significantly loaded with purely theoretical assumptions, which may deviate from the actual form of the acquired data. The goal of the development and subsequent commercialization of the card is to support global research in the field of EIT and thus increase the level of knowledge in the field of highly specialized tomographic methods. Interest is currently expected from both scientific and research institutions and the commercial sphere based on longer-term cooperation. At the national level, the system will be deployed in research on monitoring the condition of water dams in cooperation with the Faculty of Civil Engineering at BUT in Brno. Interest from Netrix, S.A. has been negotiated. in Poland, which deals with non-destructive analytical methods. Furthermore, a memorandum of cooperation was signed with the Lublin University of Technology, with which cooperation in the area of EIT methods and the use of the proposed product to support joint international research is also being negotiated. The social relevance of the result correlates with the wide applicability of electrical impedance tomography across scientific and research fields. We are currently using the designed switching card as a laboratory product to support research into optimization methods for conductivity reconstruction. In cooperation with the Faculty of Civil Engineering at the BUT, we use equipment to evaluate the homogeneity of soils on a laboratory scale [11] with planned deployment in the long-term monitoring of the condition of water structures (water dams, etc.).

TECHNICAL DESCRIPTION

The switching card for measurements in electrical impedance tomography (Fig. 2) represents a complete device necessary for current supply/excitation of the analyzed object and measurement of electrical potentials on its surface. Based on the principle of EIT, it is possible to reconstruct the specific electrical conductivity inside the monitored object using an unlimited number of electrodes thanks to the possibility of cascade connection of switch cards. As can be seen in Fig. 3, the designed card consists of two parts, namely a) a power supply and measuring part (on the left in the picture) and b) a switching part (on the right in the picture). The block diagram is shown in Fig. 1. The power supply part consists of a DDS (Direct Digital Synthesizer) signal generator, giving the user the opportunity to excite the analyzed object either with a harmonic current during the analysis of specific conductivity at one specific frequency, or also with other signal shapes for the realization of one-time experiments in a wider spectrum of frequencies. Furthermore, this part of the card contains 2 16-bit A/D converters for digitizing the voltages measured on the measuring electrodes and on the shunt for feedback control of the excitation current. The last part of this board consists of a 32-bit microprocessor STM, which manages communication with the superior system and controls the cascaded switch boards. The superior system can be either a single-board computer (e.g. Raspberry Pi) or a personal computer with an implemented electrical conductivity reconstruction algorithm from the measured data taken by the switch card. The output is always a two-dimensional or three-dimensional image of the reconstructed conductivity map inside the analyzed object.

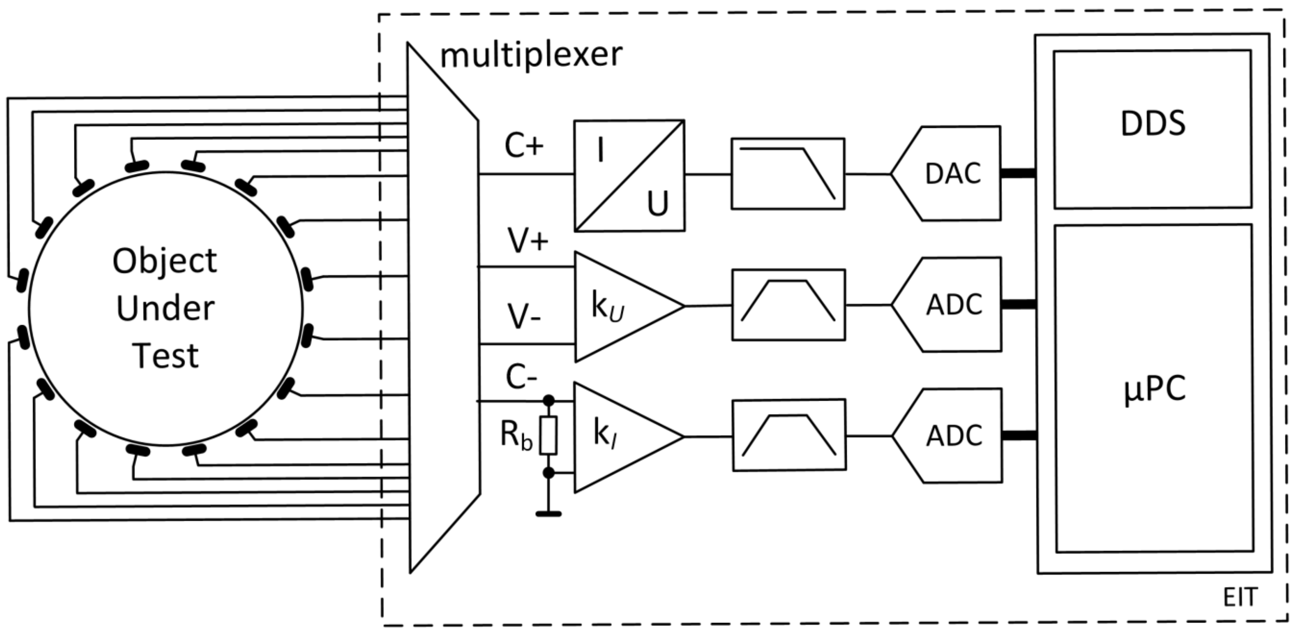
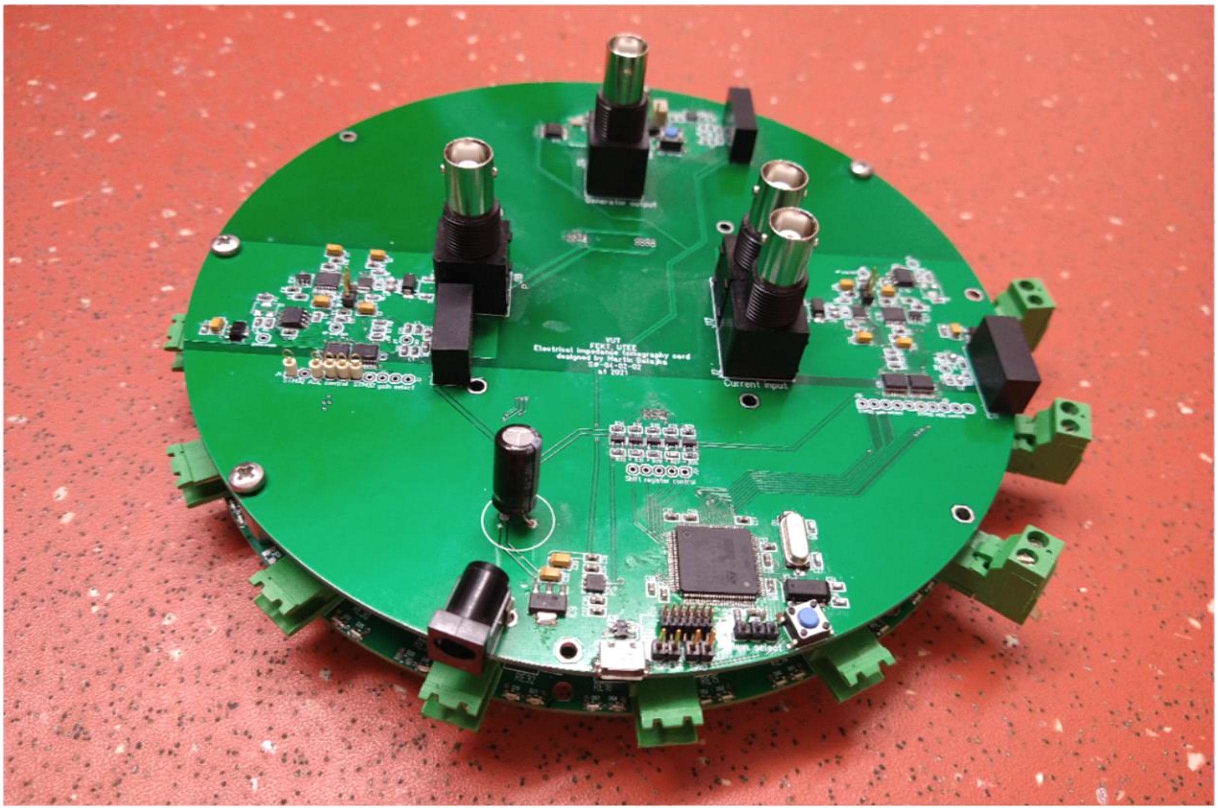


Fig. 1: Block diagram of the designed switch card for EIT.

The switching boards can serve up to 16 electrodes of the tomograph, and by simply connecting a flat cable, a virtually unlimited number of additional switching cards can be connected, each with 16 electrodes each. This makes it possible to create a very complex measuring system for increasing the accuracy of the reconstruction of the internal specific conductivity, for the realization of a three-dimensional reconstruction, or for measurements on a surface of non-trivial shape. As a concrete example of the use of EIT, the diagnosis of water flow pollution can be cited, see [12].



Obr. 2: A view of the switching tomography card; upper PCB for connecting PC and measuring devices, lower PCB for connecting measuring electrodes.

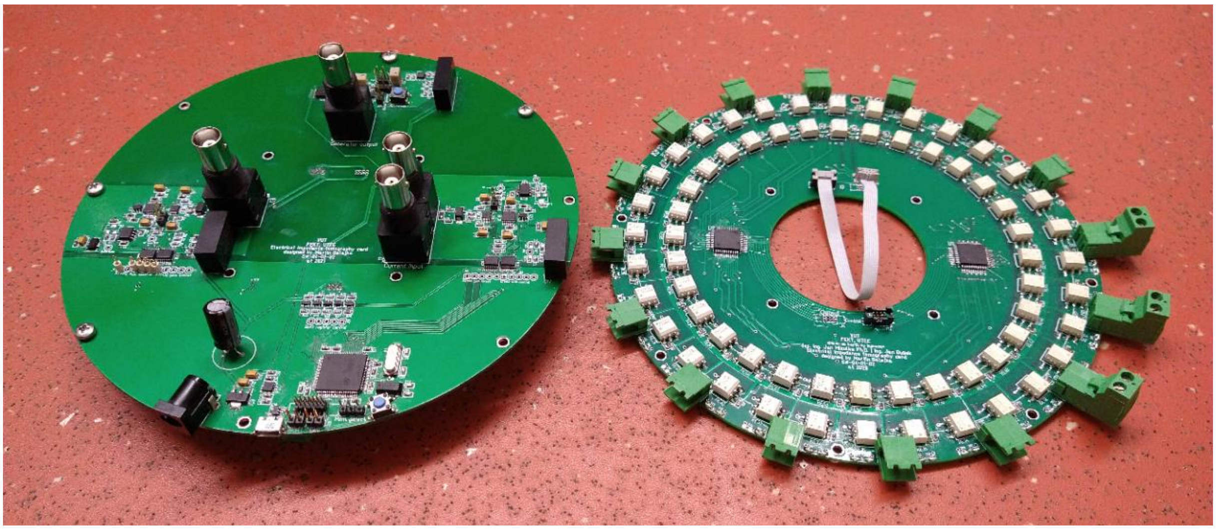


Fig. 3: An exploded view of the switching tomography card; on the left, a board for connecting PCs and measuring devices, on the right, a board for connecting 16 measuring electrodes.

The designed measuring card was implemented with several goals: financial simplicity, elimination of electromechanical components (relays), low resistance of the measuring loop in the closed state, complexity of the design without the need to include additional laboratory devices. All of these set goals were met, which makes our solution different from other commercially offered EIT measurement sets. Interesting competitive parameters of the designed card include: excitation current max. 3 mA peak at a frequency of 10 Hz – 400 kHz, resistance of the measuring loop in the closed state < 10 Ω, max. switching voltage of the measuring electrodes ± 30 V, range of measured voltages on the measuring electrodes 1 mV – 10 V, 1° phase shift resolution. The switching elements were designed to galvanically separate the measuring and power supply loops, and with regard to the requirement of low resistance in the closed state, they were implemented as bidirectional optoelectronic switches. This feature is also not standard in other commercial solutions. Selected parameters of competing systems are listed in tab. 1. A significant benefit of the proposed solution compared to competing systems is the clear specification of important parameters affecting the quality of specific conductivity reconstruction (e.g. the impedance of the measuring loop or the accuracy of the voltage/current phase shift measurement, the limit voltage of the current source), as well as a wide frequency range, limitations of electromechanical components (replacement relay optocouplers) and others. Compared to the commercially available Open EIT system [6], the proposed system also does not limit the application to the electrode system used.

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