Development of the system for visualization of electric conductivity distribution in human brain and its activity by the magnetic induction tomography (MIT) method

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Abstract. Currently rapid development of functional activity researches of human brain sets the problem of reliable and non-invasive detection of mental processes and states. At present we know some traditional methods of rapid and contactless acquisition of brain activity characteristics, such as functional tomography (fMRI) and magnetoencephalography. But these methods have low temporal resolution, complicated and ambiguous association of measured values with information processes in brain. So possibility of MIT application is investigated. Estimation of possibility of such changes registration is performed. Investigations of magnetic field configuration, schematics of transmit-receive modules and numerical algorithms are in progress. It may allow us to register high speed conductivity changes in brain tissues.

1. Introduction
Currently rapid development of functional activity researches of human brain sets the problem of reliable and non-invasive detection of mental processes and states. At present we know some traditional methods of rapid and contactless acquisition of brain activity characteristics, such as functional tomography (fMRI) and magnetoencephalography. But these methods impose some limitations on cognitive investigations due to low temporal resolution, complicated and ambiguous association of measured indirect values (i.e. blood flow changes) to real information processes in brain. Although electro encephalographic methods of analysis give us high temporal resolution, they do not allow localization of brain activity reliably and with acceptable accuracy. We are investigating possibility of MIT for brain activity visualization. This makes demands for such systems, related with spatial resolution, sufficient operation speed and receivers sensitivity to achieve maximum contrast of different biological structures. While there is no reliable data currently about relation between electrical impedance and fast activity in brain, we hope that the developed system will make it possible to detect fast variations of brain tissues conductivity related with information processes in brain.

2. Methods

2.1. MIT method
The developed method of contactless registration of brain activity is based on magnetic induction tomography technique (MIT) [1, 2], using interaction of external quasistatic high-frequency magnetic field and conductive media (brain tissues). Amplitude of used magnetic field is low, much smaller than natural Earth magnetic field. It amounts about 0.1–10 nT and depends on distance from inductor coil. These values are fully safe for human health.

Inductor coil generates magnetic field, which induces eddy currents in material. Receiver coils register these magnetic field variations. Signal produced by eddy currents are usually much smaller than primary one. Earlier we have demonstrated [3] that influence of conductive object leads to phase variation of detected signal (small quadrature component appears). It enables us to reconstruct conductivity. Therefore phase shift is proportional to the field frequency and conductivity:

$$\Delta \varphi = \omega \int W \sigma dl.$$ 

We may employ filtered back projection method [4] or artificial neural network method [5] for solving inverse problem and image reconstruction.

Spatial resolution of MIT system depends on number of independent inductor-detector combinations and coils size. Conductivity resolution depends on total working volume and on noise level of measuring system. At higher frequencies greater noise is acceptable. The measuring time is defined practically by electronics speed of operation and data transfer rate.

2.2. Current state of the MIT system
At present time multichannel MIT measuring system has designed and created. It is composed of 16 transmitter and receiver coils arranged at the 40 cm diameter circle electromagnetic screen. Acquisition time is about 0.5 sec now. It is easy to reduce it significantly by improvement of equipment and measurement and data transfer algorithm. Spatial resolution is about 5 cm. We have reconstructed conductivity distribution image inside biological objects: human thorax and brain for the first time by means of this system [6].

2.3. Lines of further development
In brief it’s necessary to:
- increase coils quantity for better spatial resolution,
- further improve measuring modules for increasing of operation speed and accuracy of phase measurements,
- update software and develop of image reconstruction methods.

Obtaining of maximum contrast MIT tomograms which reflect local hi-frequency electrical activity, particularly at frequency 40-60 Hz (brain gamma-rhythm), corresponding to post synaptic potentials and spike activity of neurons, may be reached by means of optimal combination of such parameters as magnitude and configuration of excitation magnetic field, operating frequency and sensitivity of receivers. These parameters may vary depending on tissue under investigation and changes owing to biochemical and physiological processes. Thereby we plan to work out new experimental prototype of multifrequency MIT tomograph with better spatial resolution (about 1 cm) due to 64 coils with smaller size. Temporal resolution will be not worse than 5 msec. Estimation of optimal parameters for brain activity visualization will be carried out on experimental models and real objects during psychophysiological experiments.

2.4. Design of the new MIT system
Coils, as before, will be situated at circle electromagnetic screen. Such configuration provides protection from external electromagnetic fields and the best system sensitivity for brain investigation. We plan to increase coil quantity 4 times as many (from 16 to 64). And coils diameter will 4 times
less. We need to increase power in inductor coil for phase measurement accuracy enhancement (see figure 1).

We will solve this task by means of power high-frequency amplifiers, which are capable to give higher power to output coil (inductor). Optimal quantity of turns will be chosen from operating frequency value and characteristics of specific amplifier. Microcontroller produces input signal for the amplifier and controls its working regime. It is necessary to use more sensitive receivers and thorough filtering in input and following cascades of receivers.

**Figure 1.** Block diagram of the MIT channel module.

It is necessary to obtain high temporal resolution (or operation speed) during measuring and data saving only. Operating frequency should be in 10-20 MHz range. For better results of amplifying, filtering and digitizing of the receiver coil signal we need to convert it to lower frequency (e.g. 450 kHz). At this frequency minimal data acquisition time is about 1.3 ms (for 10 periods of averaging). This is suitable value for investigations of 40-60 Hz processes. For significant reducing of acquisition time digitizing of receiver’s signals should be carried out in parallel at all 64 modules. Using of superheterodyne receivers allows us to depart from using expensive hi-speed DACs and processors. But we can measure sufficiently quickly even at lower frequency.

Measurements results in each channel are accumulated in memory of corresponding microcontroller. It will be preferable to calculate two quadratures in the microcontroller rather than transfer ADC counts in real-time. It allows us to reduce data volume significantly. When storing data as 32-bit digits, 1 data set (frame) occupied 60 Kbytes only. After finishing of all measuring session, data from all modules are passed to PC through USB and saved here. Data processing and reconstruction will run later, not in real time.
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