Buletinul Ştiinţific al Universităţii "Politehnica" din Timişoara

Seria ELECTRONICĂ şi TELECOMUNICAŢII
TRANSACTIONS on ELECTRONICS and COMMUNICATIONS

Tom 58(72), Fascicola 2, 2013

Active electrodes for EEG

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Abstract – The functional exploration of detection of the bioelectric activity along the scalp, it's graphic representation and the analysis of the obtained signal is called *electroencephalography (EEG).* An EEG recording is made using electrodes placed on the scalp.

I. COLLECTING THE BIOELECTRICAL SIGNALS AND USED ELECTRODES

An electrical conductor for which a contact with an electrolyte is assured is called an electrode. At the contact of the electrode with the electrolyte phenomena that transform the ionic conduction in eletronic conduction appear. There is thus a shift of electrons from the metal to the electrolyte and of ions from the electrolyte towards the metal in order to achieve chemical equilibrium.

The interaction between the metal and the electrolyte causes a local change in concentration of ions in the solution next to the metal surface, appearing as a potential difference between the electrode and the electrolyte called *electrode potential*. The lectrode potential can be measured with a reference electrode made of platinated platinum (platinum coated by electrochemical deposition with a thin layer of spongy platinum, called black platinum for increasing the contact surface) over which is blown hydrogen gas at 1 atm.

The value of this potential is a function of the electrode material (for AgCl is 0.233 V).

In order to eliminate the drawbacks related to the variation of the electrode potential and the use of electrodes to measure the DC signals or low frequency it is good:

- to use metals with low electrode potential;
- collections to be made with electrodes of the same material;
- to use electrodes made of metal covered with heavy soluble salt having a common ion with the electrolyte(second kind electrodes).

If between the electrode and the electrolyte there is no running current, at the electrode's output we will have the electrode potential. Having a current flow results in a change in the load distribution inside the solution in contact with the electrodes, so the measured potential changes.This effect is called *polarization* and might change the electrode performance.

From this point of view there are two electrode cathegories:

a) polarized - in which current flow determines load distributoin changes at the interface, determining a current change;
b) non-polarized - allowing the passage of current through it without a load distribution change at the interface so without a current modification.

In practice, it is preferred to use a non-polarized electrode because:

- the movement arifact is reduced;
- electrode impedance change with frequency is small;
- electrode noise is small.

In Fig.1 we have Ag/AgCl electrodes with different sections, electrodes with performance close to the perfectly non-polarized ones.

When operating at low voltages and currents, electrodes can be represented by the equivalent circuit from Fig.2.

In the equivalent schematic we have:

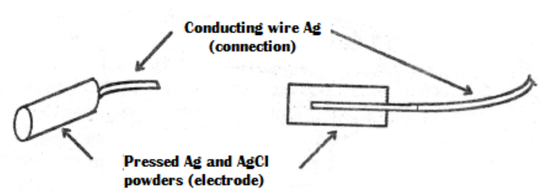

Fig.1. Ag/AgCl electrodes

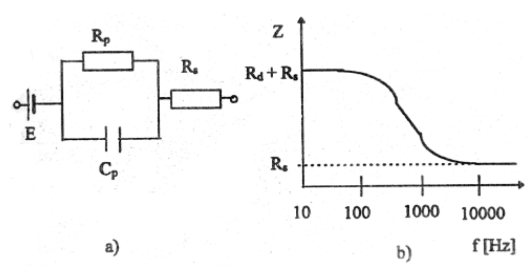

Fig.2. a)The equivalent schematic of a bipotential electrode; b) The electrode impedance function of frequency

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- the power supply E representing the electrode potential;
- R_p and C_p representing the impedance associated to the effects from the electrolyte-electrode interface and it's polarization;
- R_s the resistor associated to the effects from the interface and the electrode material's resistance.

The electrodes used for the collection of biological signals are silver chlorinated. For stimulation, electrodes must be of metal or alloys with small polarization voltages at high current densities, and to be free of toxicity problems. The platinum and iridium alloy meets these requirements.

In order to determine the electrode potential, between the metal electrode and skin a filter paper is inserted, or even a gauze soaked in alcohol, or an electroconductive paste so that if the skin is sanitized with alcohol a lower resistance is obtained at the interface and the impedance becomes more stable.

In Fig.3 is presented a situation in which two electrodes connected to a power supply are used. The perturbation sources were taken in consideration.

The notations made in the figure are:

- Z and e - impedance and the bioelectric signal generator's voltage;
- E_1 and E_2 - electrod potentials;
- Z_1 and Z_2 - impedances of the electrodes and skin interfaces;
- V_{mc} and Z_{mc} - voltage and common mode impedances from the signal source;
- Z_m and V_m - impedance and voltage of the ground circuit;
- Z_{i1} and Z_{i2} - coupling impedances of the electrode cables with the external perturbation sources;
- C_1, C_2, C_{12} - parasite capacitors of the electrode cables and their variations;
- V_z and I_z - equivalent noise sources at the amplifier's input;
- C_{in} and R_{in} - amplifier's input capacitor and resistor.

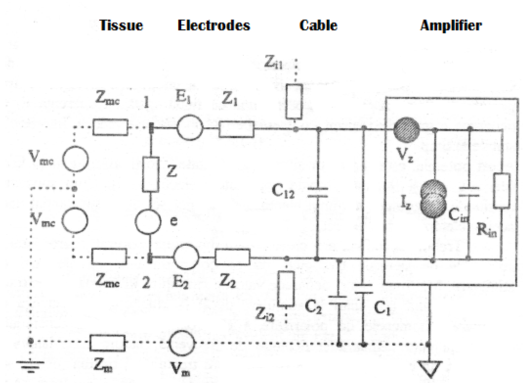


Fig.3. The equivalent schematic for collecting the bioeletric signals

II. ELECTROENCEPHALOGRAPHY

The EEG is a mixture of periodic or cvasiperiodic low frequency signals, with amplitude between 10-100 μVpp. The EEG trace represents multiple tipes of waves which can be separated on frequency bands using spectral analysis, Fig.4.

This specific waves are:

- α rythm - banwidth between 8-13 Hz and appears during wakefulness and relaxation. For deep relaxation the 10 Hz waves are predominant, and are the same with the resonance frequency of the terestrial magnetic field;
- β rythm - bandwidth between 14-32 Hz, amplitudes below 30 μVpp and is ascociated to cognitive thinking;
- γ rythm - bandwidth between 33-55 Hz;
- δ rythm - bandwidth between 0.5-3 Hz, ampitudes of 50-150 μVpp and it appears at children and adults during sleep. For an adult in wakefulness it is patologic.
- θ rythm - bandwidth between 4-7 Hz, amplitudes of 30-70 μVpp, are found usually at children and rarely at adults. A high share at an adult denotes mental problems.

The collection systems of the EEG signal are standardized (Fig. 5 and 6). The electrodes are called after the collecting zone: frontal electrodes - F, temporals -T, centrals - C, parietals - P, occipitals - O, and the refference electrode is noted with A. The ground electrode is placed on the right leg, like in ECG.

The *unipolar collection* amplifies the electrod signal towards the reference. The collection with *median point* of reference uses the mediation of signals from all encephalic eletrodes using a resistive net of sumation. The bipolar collection allows a better location of the encephalic phenomena because the useful signals can be in antiphase and so the artifacts cand be isolated.

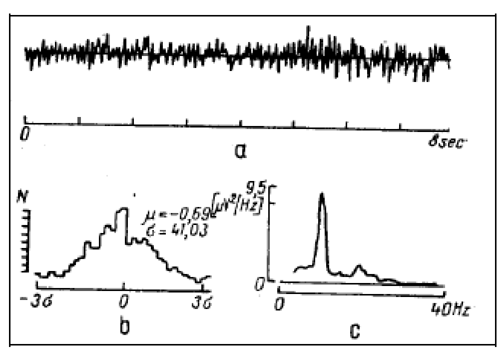


Fig.4. a) EEG; b) amplitude distribution; c) spectral density

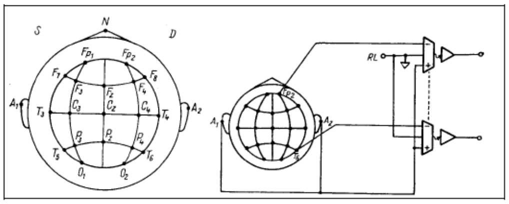
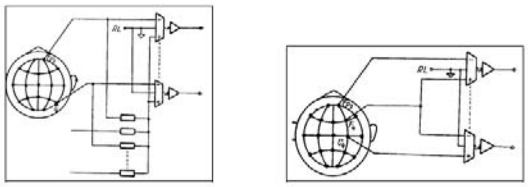


Fig.5. EEG electrodes placing and the unipolar collection.



(a) (b)

Fig.6. a) Collection with median reference point; b) bipolar collection

III. ACTIVE ELECTRODES

In most eeg readings passive electrodes are used. They are cheap, easy to manufacture and maintenance. They require however special skin preparation in the spot under electrode, and a special paste is also required to lower impedance between electrodes and skin. Those requirements are usually acceptable, but not always.

An active electrode is an electrode that requires no skin preparation. This is possible with a preamplifier placed very close to the skin. High dry skin impedance can be omitted by using an amplifier with very high input impedance.

Another reason to use active electrodes is safety. Because the dry skin-electrode impedance is very high (a few MΩ) then the isolation barrier is much higher and chances for an electrocution are much smaller comparing to passive electrodes.

The concept of active electrodes involves introduction of a unity gain op-amp physically built into the electrode, but this results in a high input impedance. Electrode/skin impedances are in series with input impedance of the op-amp- the higher electrode/skin is the less signal will get to the op-amp. So it is important to have low and equal impedances.

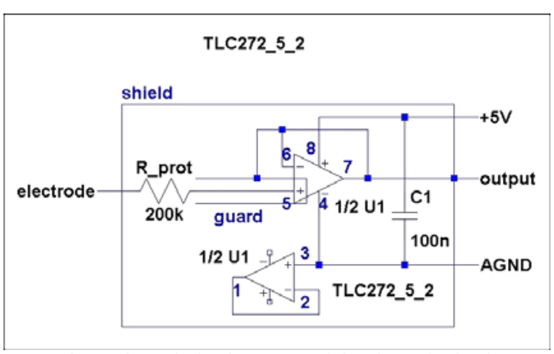


Fig.7 Schematic for the EEG modular electrode circuit

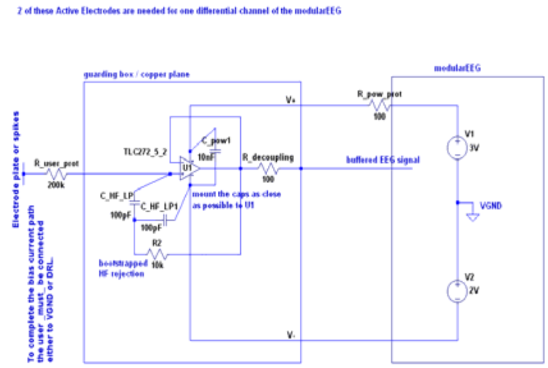


Fig.8 The improved schematic of the circuit after which the PCB is made

This is a first idea for the circuit to build the modular EEG electrode. An improved circuit is presented in Fig.8.

IV. EXERIMENTAL RESULTS

There were 3 subjects from which data was collected. Measurements were taken by dry active electrodes. All the measurements were taken using a modular EEG device.

To check performance of electrodes two tests were made:

Eyes open/ eyes closed test : In this test it was expected that when subject will hold eyes closed - there will be more alpha activity than in time when subject had eyes open, Fig.9.

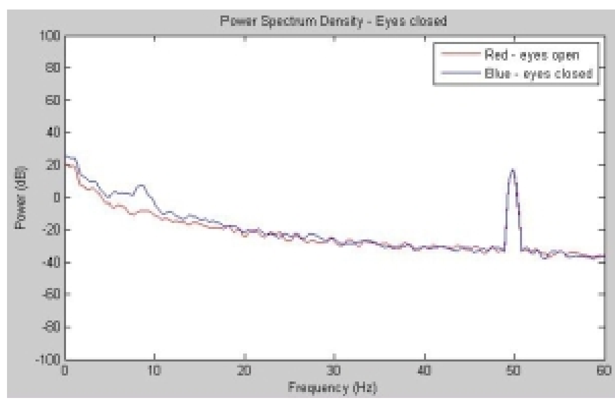


Fig.9 Eyes open/eyes closed test

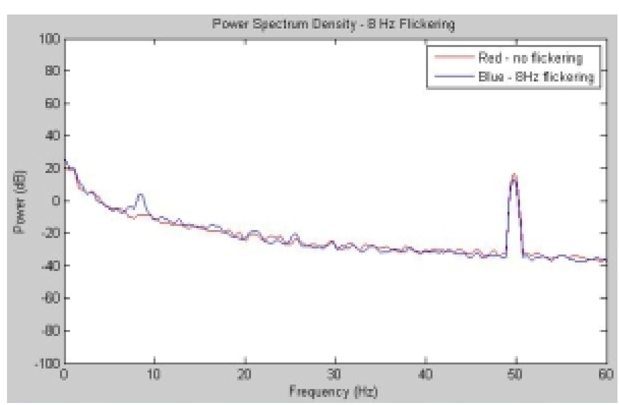


Fig.10 Flickering light test

Flickering test: In this test it subjects were asked to observe flickering screen, Fig.10. It was expected that 8Hz flickering will induce ~8Hz brain activity.

V. CONCLUSIONS

The Active Electrode is a superior solution for the problem of interference pickup of the cables, providing the best possible suppression of interference by impedance transformation directly on the electrode. The active electrode has an output impedance of less than 1Ω, ensuring that the signal in the cable is fully insensitive to interference. In addition, the active electrode has crucial advantages with respect to shielding and guarding techniques:

- Highest possible input impedance because of minimal signal path length between electrode and first amplifier stage.
- Minimal stray-capacitances of the input.
- Low impedance output of the electrode allows the use of reliable, cost-effective light-weight cables (no need for expensive low-noise heavy coax cables).
- Low impedance output of the electrode combined with matched low input impedance of the AD-box eliminates contact problems in the electrode connectors (no "cracking" when you move the electrode cables or connectors as seen with all passive electrode systems).
- No need for delicate expensive coaxial plugs. Active electrode systems can use convenient multi-pole plugs.
- Low impedance output eliminates artifacts by cable movements. (all systems with shielded coax cable are particularly sensitive to this problem because of micro phony and piezo electric effects generated by the isolation layer between the inner core and the shield).
- No danger for amplifier instability because of the absence of complicated feedback loops with unknown parameters (i.e. electrode impedances and subject stray-capacitances).A cable shield driven by a guarding circuit forms a loop with positive feedback which may become unstable with particular combinations of electrode impedances and subject stray-capacitances.

The PCB for the modular EEG is presented in Fig.11. And the final form of the modular EEG is shown in Fig.12.

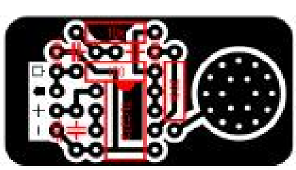


Fig.11: PCB Layout

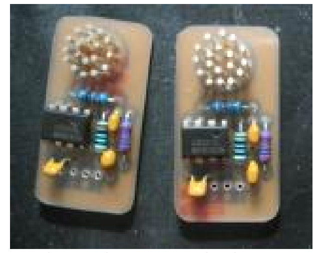


Fig.12 The two populaed PCBs

VI. REFERENCES

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