ELECTRIC FIELD MEASUREMENTS IN SEA AND GROUND: RECENT DEVELOPMENTS AND EXPERIMENTAL RESULTS

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ABSTRACT

The measurements of slow fluctuations of weak electric fields in the conductive media (soil, water, space plasma etc.) is one of the most difficult problems of measurement science. That is because of extremely low signal-to-noise ratio, by this both useful and noise signals have practically the same frequency band.

Up to now are two possible methodologies of such measurements. First one mostly applied for sea bottom electrometers includes periodic commutation of measuring electrodes by mechanic switch gating in and out the useful signal on the noise background. Second one mostly used in field experiments foresees the augmentation of signal-to-noise ratio by separation of the measuring electrodes by great distance, so raising the useful signal on almost the same level of electrodes noise. The ways to improve the efficiency of both approaches are analyzed in the paper.

1. INTRODUCTION

The measurements of electric fields in the conductive media (soil, marine water, space plasma) is one of the most complicated metrological problems. Because of considerable conductivity of all these media the values of electric fields are very low and need high sensitivity of the measuring instrument. Also it is necessary to note that there is no physical sensors measuring directly the electric field intensity E. This value is determined only by calculations on the base of mathematical equations, relating the components of the vector $\vec{E}$ with other physical values, the direct measurement of which is possible [1]. In most cases following equation, e.g., for X component of $\vec{E}$, is used:

$$E_x = \frac{\varphi_{x1} - \varphi_{x2}}{x}, \tag{1}$$

where $\varphi_{x1,2}$ are electric potentials in the points 1 and 2 along X axis, separated by a distance x.

As far as electric potentials difference has to be determined, there is the simplest way to make it with the help of a couple of electrodes, being in direct contact with the medium and placed in points 1 and 2 respectively. Unfortunately, together with ensuring of φ_{xi} sensing, the direct contact with the medium gives rise to the side offset contact potential difference between the electrode and the medium or to the own potential of the electrode φ_e. Taking this additional potential into account, we get on the basis of the equation (1):

$$E_x = \frac{(\varphi_{x1} + \varphi_{e1}) - (\varphi_{x2} + \varphi_{e2})}{x} = \frac{(\varphi_{x1} - \varphi_{x2}) + (\varphi_{e1} - \varphi_{e2})}{x} \tag{2}$$

In the last line the first term in brackets is the useful signal U_x and the second one - the noise U_n. The separation of these values in order to obtain high signal/noise ratio is extremely difficult problem when extremely low frequency fluctuations of electric field are investigated. That is because U_n spectrum is mainly centered in the same frequency band and its power is much higher as this of U_x. So, all skill of the designer of the device for the U_x measurement in the conductive media is concentrated upon the methodology of U_n reduction. For each medium these methods are different, having one common part - to try to decrease as much as possible the φ_{ei} value or at least, according to the second bracket in the equation (2), to make them as equal as possible for two electrodes composing the pair.

2. ELECTRIC FIELD MEASUREMENTS IN THE SEA

The most complicated is the situation with the E investigations in marine water. Because of very high conductivity (typically about 3-4 Sim) the E levels are very low - from unites to fractions of microvolts per meter, whereas the U_n signal is about hundreds of microvolts in the best case. In such situation the only possible way to measure U_x is to separate U_x and U_n in external circuit, because as aforesaid not possible to do it at the output of the measuring instrument. The unique reliable realization of this procedure is mechanical chopper, which commutates the electrodes in one way to the external source (water) via so called hydrochannels forming the base x and in the second way separates the electrodes from the external source [2]. In the first case we have the output signal according to the equation (2), in the second one - according to the next expression:

$$U_n = \varphi_{e1} - \varphi_{e2} \tag{3}$$

Subtracting (3) from (2) we get desired value of E (in all cases it is supposed that the reference base x of the measuring instrument is well known).

Up to now one of the most reliable constructions of marine electrometer was built by J. Filloux [2] and the results of its application showed that principally the long-term measurements of electric field in sea water are possible. Since that time some other more or less successful attempts were made in different countries and manufactured constructions do not differ in principle from that of Filloux. Main problem what was more or less successfully competed was to provide good and reliable contact of mechanical chopper to the frame in closed position in order to provide full length of the base **x** and low resistance between electrodes in open position in order to separate them from external signal. A new principle of chopper construction, eliminating this problem, was developed in FSU first in Novossibirsk [3], then by the IZMIRAN group [4]. Instead of tight closing of electrode chamber this construction is principally unhermetized. The modulation of the input signal is executed by changing the resistance R of the path between electrodes: in «open» position R is much less than the resistance of hydrochannels R_c and in the «closed» position R has to be much more than R_c. The modulation coefficient can be achieved as much as 99%. Such system was constructed and showed good results. Its main disadvantages are principally short span in order to fulfill $R >> R_c$ and the necessity of mechanical driver. All the disadvantages of the mechanical device with moving parts under the high pressure and in such aggressive medium as marine water are clear.

Numerous attempts were made to use the electronic commutator instead of mechanic one. One of the proposed solution was the use of so called ring magnetic modulator as contactless electrometer [5] which reacts on the current density flowing through the inner hole. Unfortunately, theoretical limit of sensitivity of the device doesn't allow to get the resolution better than unites of mkV/m with reasonable size of this modulator.

Another attempt was to replace the mechanical commutator by the electronic one [6]. Its principle was to use additional pair of electrodes for periodic shielding of measuring electrodes from the signal. The investigation showed that unfortunately there is a deadlock solution because by no way the possible number of equations could be made equal to the number of unknown variables.

For the moment all activity in this branch is concentrated on the chopper construction improvement and the input amplifier development [7]. In the last direction new version was created, based upon the AD204JN insulation amplifier. The comparative set of amplifier's parameters for marine electrometer are assembled in the Table 1.

Table 1. Low noise amplifier with galvanic insulation

parameters	previous	present	new design
galvanic insulation	no	yes	yes
gain	100	500	100-1000
min. input impedance	50 Mom	15 Mom	20 Mom
input offset voltage	50 mcV	10 mcV	2 mcV
temperature drift of offset voltage	1 mcV/ °C	0,5 mcV/°C	0,05 mcV/°C
input bias current	50 pA	10 pA	10 pA
temperature drift of input bias current	20 pA/°C	2 pA/°C	2 pA/°C
noise voltage	$200\ nV/\sqrt{Hz}$	$15\ nV/\sqrt{Hz}$	$8\ nV/\sqrt{Hz}$
noise current	$30\ pA/\sqrt{Hz}$	$5\ pA/\sqrt{Hz}$	$3\ pA/\sqrt{Hz}$

3. ELECTRIC FIELD MEASUREMENTS IN THE GROUND

The very long period E measurements (about hours and days) are most often executed in the soil for the purpose of deep sounding of the Earth's crust. The best solution until now for U_n impact decreasing was the x base elongation for hundreds meters for field systems and about few kilometers for stationary ones. By this U_x term managed to reach big enough values whereas U_n term has to be not influenced by the distance between electrodes. Practically it is not so because of different soil, humidity, temperature etc. at so large distances, what leads to the considerable raise of U_n.

So, to have the electrode line length reasonably small (about 100 m or less) can be recommended. By this the requirements to have as low as possible electrode drift or the differential drift of electrode pair become very important.

In spite of some progress in the electrodes construction their drift still remains much greater than useful signal. The application of special PC-based methodology of matching pairs selection, which requires a set of laboratory experiments, allows to reduce considerably the differential drift. The efficiency of this methodology is illustrated by Table 2. Here the results of the choice of 4 matching pairs from 14 electrodes are presented, by this in column a) the drift data for selected matched pairs are given and in column b) the data for the same electrodes but randomly combined. The selection was made basing on 20-days laboratory tests of the whole electrodes batch.

Table 2. Drift data for electrodes

a)

Electrode No	Drift, mcV
4 - 7	17.2
1 - 10	27.4
5 - 12	32.4
6 - 13	49.2

b)

Electrode No	Drift, mcV
1 - 4	372
7 - 10	363
6 - 12	86
4 - 13	105

So, it is evident that this methodology allows to select matched pairs with enough low differential drift.

But still more important question is the methodology of electrodes conservation and installation which has to be directed to the maintaining of achieved low drift level. Best way to stock the electrodes between operation periods is to keep selected pairs in the pure solution of the salt with the same radical as manufactured electrodes. In our case for Cu-$CuSO_4$ electrodes $CuSO_4$ solution is used. Then following proceeding by installation is recommended.

- Look for the place for electrode installation with preferably clayey ground and dig the hole up to the wet ground, but not shallower than 70 cm.
- Make a deepening in the bottom with about the same diameter as electrode and put there the electrode - sensitive part up!
- Fill the hole bottom by preliminary prepared suspension till the sensitive part will be covered by 3-5 cm layer, wait about 10-20 minutes and bury the hole.

To make intimately the suspension is also very important. It has to be made from the ground taken from nearest proximity to the electrode and $CuSO_4$ conserving solution and carefully stirred in plastic vessel.

A good indicator of properly placed electrode pair is its low output resistance which has to be around 1000±500 Ohm. With time this value can increase up to 2-3 kOhm and if the output resistance becomes greater than 5 kOhm then the electrodes have to be reinstalled. Certainly the output resistance measurement method in no way has not to allow the loading of electrodes by external currents or their short-circuiting. Many possibilities to realize this method in given restrictions can be proposed.

4. CONCLUSION

The problem discussed in this paper still is a open question in metrological practice. Also the calibration of electric field meters, about what was nothing mentioned, is may be the most difficult task, solved very poorly. Nevertheless the importance to study experimentally the electric fields forwards still new attempts in this branch and more or less reliable experimental results are from time to time reported. The task of the authors was to show that the methods and devices described in the paper do can provide the electric field measurement both in the sea and in the ground with enough high for practice quality.

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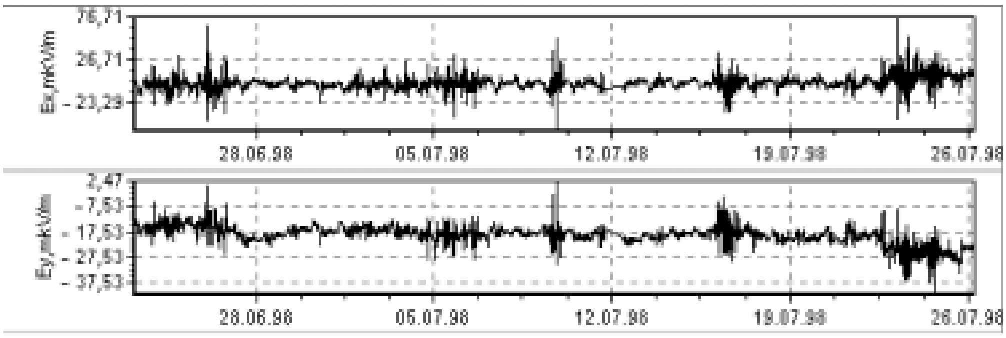

Fig. 1. Experimental data of electric field measurements.

LCISR has already long practice to manufacture and to use Cu-$CuSO_4$ electrodes in field practice, mainly for magnetotelluric study. An example of field experimental data obtained during summer 1998 campaign in Estonia is given on Fig. 1. The data was not subjected to any processing and both low level of measured signals and practical absence of long-term drift are clearly seen.

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