Short note on electrode charge-up effects in DC resistivity data acquisition using multi electrode arrays

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Published in:
Geophysical Prospecting

DOI:
10.1046/j.1365-2478.2000.00172.x

2000

Geophysical Prospecting, 2000, **48**, 181–187

Short note on electrode charge-up effects in DC resistivity data acquisition using multi-electrode arrays[1]

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Abstract

The measurement sequence used in DC resistivity data using multi-electrode arrays should be carefully designed so as to minimize the effects of electrode charge-up effects. These effects can be some orders of magnitude larger than the induced signal and remain at significant levels for tens of minutes. Even when using a plus-minus-plus type of measurement cycle, one should avoid making potential measurements with an electrode that has just been used to inject current, as the decay immediately after current turn-off is clearly non-linear.

Introduction

DC resistivity data acquisition using computer-controlled multi-electrode arrays is becoming increasingly popular, as it allows efficient and complex data acquisition strategies that are inconceivable using manual methods. The trend is expected to continue because there is:

- an increasing demand for detailed knowledge about subsurface features in environmental, hydrogeological and engineering applications;
- continued development of efficient techniques for data inversion and imaging;
- a variety of data acquisition systems which are commercially available.

However, as the number of possible electrode permutations increases rapidly with the number of electrodes, optimization of the data acquisition technique is necessary, in order to gather as much information as possible in a limited time, without loss of data quality. For a general electrode array, it is not practical to have separate current and potential electrodes, and instead all electrodes must serve as both current and potential electrodes during the data acquisition procedure. Electrode charge-up effects, or electrode polarization, is a well-known phenomenon in induced polarization (e.g. Bertin and Loeb 1976; Sumner 1976; Parasnis 1997). The electrode polarization is attributed to charge build-up on the interface between the conducting metal of the electrode and the surrounding ground of less conductance. These effects, which occur

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when an electrode is used for transmitting current, should be taken into account if the same electrode is subsequently used for measuring potentials.

One important factor in this context is the applied measurement cycle type. In general, readings from current transmitted with reversed polarity are averaged to balance out natural and man-made potentials, which may be much larger than the induced potentials. A typical current pulse length can be approximately one second. In order to suppress low-frequency variation in the background potentials, a binomial-filter type of measurement cycle can be employed (Madden and Cantwell 1967), where the three-term filter with coefficients $(1, -2, 1)1/4$ suppresses linear terms. In practice, the measurement cycle may consist of a positive pulse, a double negative pulse and again a positive current pulse, referred to here as the plus-minus-plus type. The transmitted current sequence for a plus-minus-plus cycle and a sketch diagram of the corresponding recorded potentials are shown in Fig. 1, where IP effects, linear drift and noise are indicated.

Test set-up

The tests presented here were carried out on a small grass-covered area on the university campus in Lund. The set-up included four steel electrodes with a separation of 25 m between each to carry out normal and reciprocal Wenner measurements. The ground consists of clayey till overlying shale, and there may be some fill material. At the time of the experiment the ground surface was partially frozen.

A series of data was taken in order to assess the influence on the measured data from electrode charge-up effects, if electrodes used to transmit current were used to measure potentials immediately after the current was switched off. One example of the results is presented below.

Result

First, measurements were taken with a standard Wenner array for about 4.5 minutes, seen as the first (horizontal) part of the curve in Fig. 2. Here, the background potentials are very stable and the measured effect of the transmitted current is seen as a square-wave-like pattern. Note that the potential induced by the transmitted current is only a fraction of the full scale of the diagram. Any ambient noise picked up by the potential electrodes is superimposed on the signal displayed in Fig. 2, and it is obvious from the consistent record that electrical disturbances from, for example, power supply cables are dealt with by the filters of the recording voltmeter.

Thereafter current was transmitted through the potential electrodes for a few cycles of measurements, followed by normal Wenner measurements again. As shown in Fig. 2, the electrode charge-up is more than 0.3 V in this case, which is more than 30 times larger than the induced potential variations. It is also evident that significant effects due to the current transmission persist for tens of minutes. Similar magnitudes have been recorded at other locations in southern Sweden. It is easy to envisage measurement

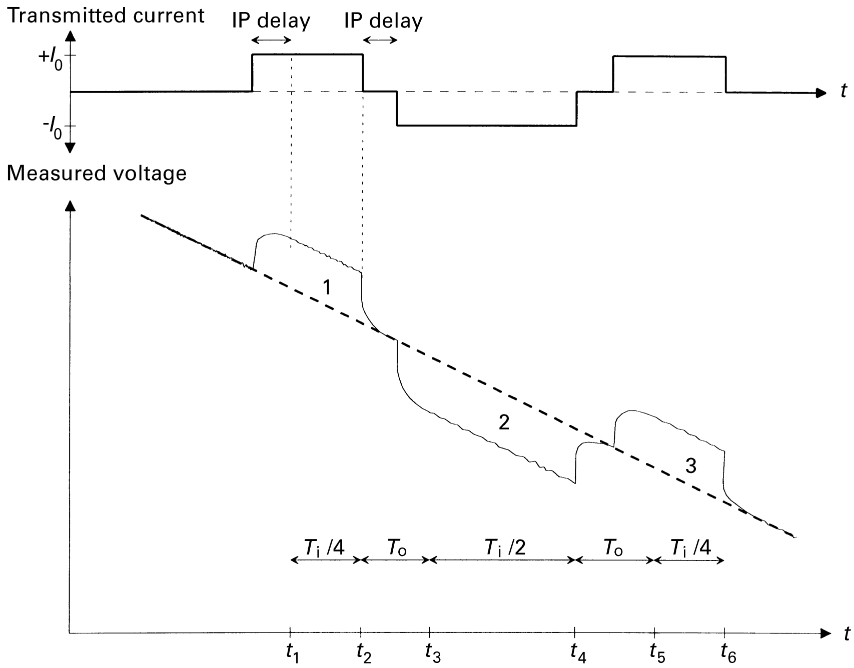

Figure 1. The transmitted current sequence for a plus-minus-plus cycle with a sketch diagram of the corresponding recorded potentials, where IP effects, linear drift and noise are indicated. T_i indicates potential integration time, and T_o indicates time where potential measurement is off (after Krill 1979).

situations with lower induced signals, for example, using longer electrode separations or where resistivities decrease with depth, and the same magnitude of charge-up effects where the relative effect would thus be larger.

Figure 3 shows a detail of the measured potentials in the time interval 6–8 minutes. A repetition of the plus-minus-plus type of measurement cycle was employed. In the diagram, the positive peaks consist of data from two consecutive cycles, and the small 'step' is due to the time interval when the current is switched off between the cycles.

Measuring sequence

The electrode charge-up effects have practical implications regarding the measuring sequence in a multi-electrode data acquisition system. Even if a plus-minus-plus type of cycle is employed, it is obviously inappropriate to use an electrode for potential measurements immediately after transmitting current through it, as strong non-linear decay is present immediately after the current is turned off. Thus, in order to avoid data acquisition errors, it is necessary to use measurement strategies that allow the charge to decay sufficiently so that further decay can be regarded as essentially linear within each measurement cycle.

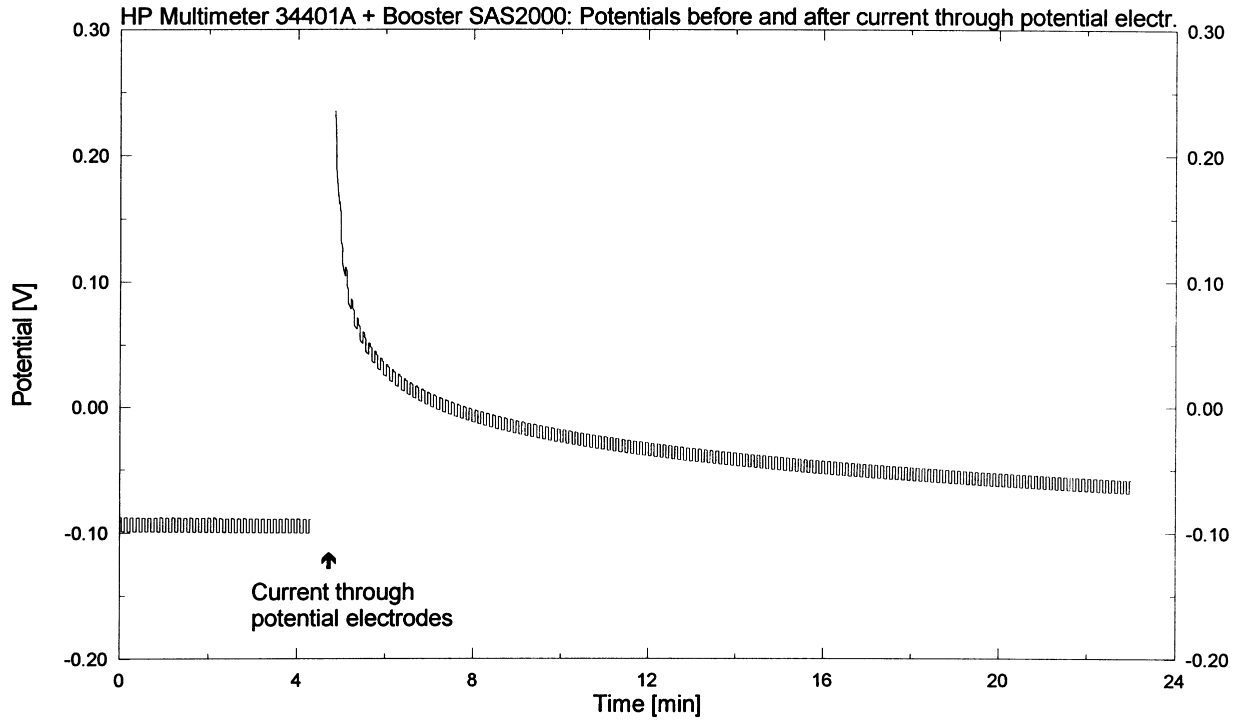

Figure 2. Measured potentials before and after current injection through the potential electrodes, with a current of 20 mA. Note the very significant charge build-up due to the current injection. The positive peaks consist of data from two consecutive cycles (plus-minus-plus type of cycle).

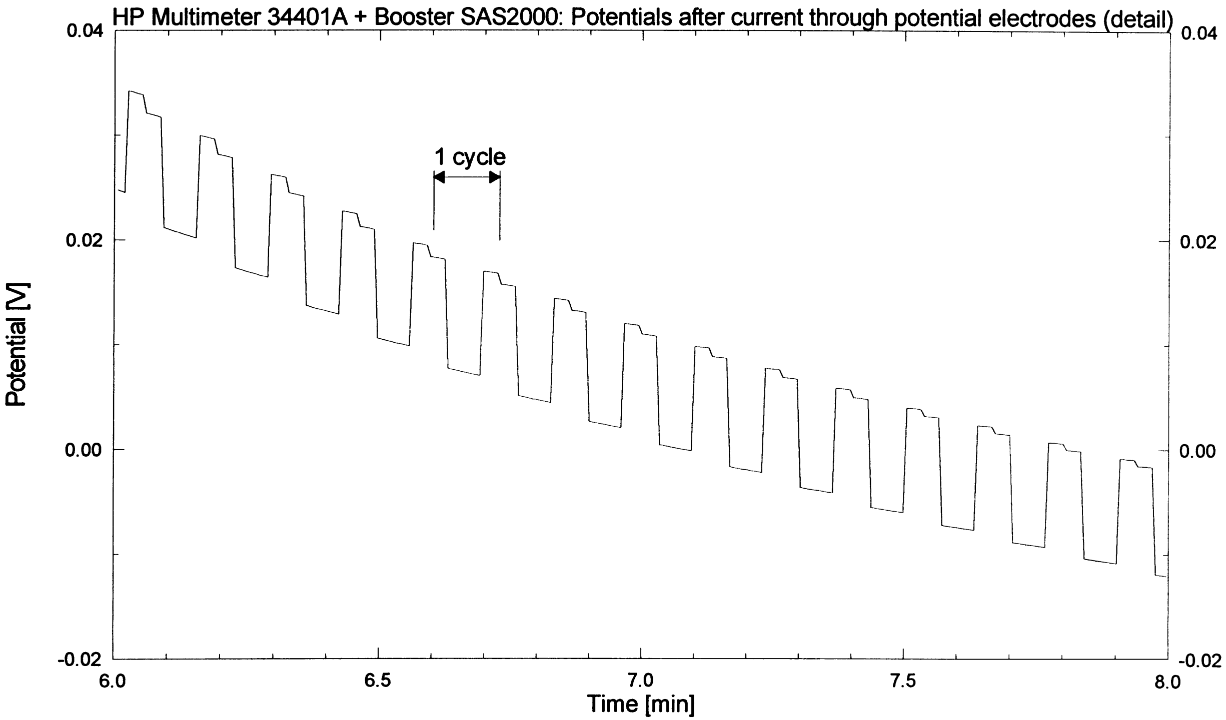

Figure 3. Detail from Fig. 2 showing measured potentials with a transmitted current of 20 mA. Note that the positive peaks consist of data from two consecutive cycles (plus-minus-plus type), where the small step is due to the time interval when current is switched off between the cycles (IP delay time and current-off time not recorded).

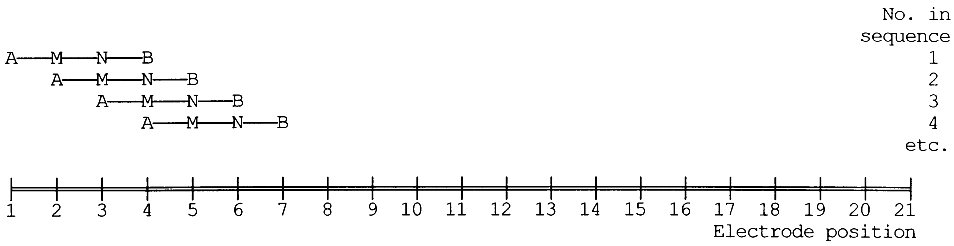

Figure 4. A Wenner array measurement sequence (A, B = current electrodes; M, N = potential electrodes) used for reading potentials with an electrode immediately after it has been used for transmitting current.

For the Wenner array, simply moving the four electrodes forward one step for each four-electrode combination to be measured (Fig. 4) would result in the potential electrode N being strongly affected by its use as current electrode B in the previous measurement. The strategy illustrated in Fig. 5 avoids this, and allows the steepest part of the decay curve to pass before potential readings are taken with an electrode. Similar schemes can be designed for other four-electrode arrays.

For the pole–pole array it is easy, by starting with the current electrode in position 1 and then moving it up one step at a time, to take all potential readings at higher electrode positions before moving the current electrode position again. If reciprocal readings are required for data quality control purposes, care must be taken with readings for electrode positions behind the current electrode, as charge-up effects will affect these.

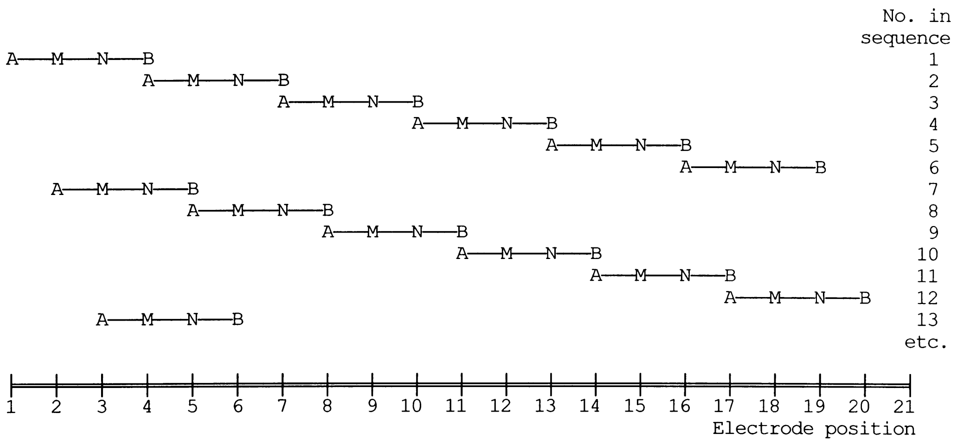

Figure 5. A Wenner array measurement sequence (A, B = current electrodes; M, N = potential electrodes) that avoids reading potentials with an electrode immediately after it has been used for transmitting current (Dahlin 1993).

Conclusions

It has been shown that electrode charge-up effects, orders of magnitude larger than the induced signal, that remain at significant levels for tens of minutes can appear in natural soils. In order to avoid adverse effects on data quality when measuring with a multi-electrode system, these effects must be considered, as well as other noise sources such as telluric currents, self-potentials, induced polarization effects, electrical power lines, etc. Besides using a proper plus-minus-plus type of measurement cycle, it is important to design the measurement sequence so as to avoid making a potential measurement with an electrode which has recently been used for transmitting current in the ground.

Acknowledgements

The work for this paper received financial support from the Swedish Geological Survey (SGU) and the Swedish Environmental Protection Agency (AFR/Naturvårdsverket).

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