Colinear null arrays in geoelectrics

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SUMMARY

The term “null arrays” is used for geoelectrical arrays, where the expected (directly measured or somehow derived) quantity is zero over a homogeneous half-space. The geometrical null arrays, where the zero potential difference is due to a proper geometrical setting of the electrodes, represent the most direct realization of the null array principle.

Colinear geolectric null arrays form an alternative group of noncolinear geometrical null arrays. We propose two colinear null arrays: the so-called Midpoint null array and a slightly modified version of the Wenner-γ null array (the Wenner-γ quasi null array). They have several benefits over already known, noncolinear geometrical null arrays, as follows: they are informative not only in three-dimensional but already in two-dimensional problems; their field realization and interpretation is simpler than those of the noncolinear null arrays.

Moreover, both of them can be easily integrated in multielectrode systems, and both of them can be used in combination with the conventional Wenner array. We present the basic features of colinear null arrays (1) by using parameter sensitivity maps, (2) by a two-dimensional model analysis, and (3) by field tests, where well measurable and geologically meaningful anomalies were observed.

Keywords: null arrays, geoelectrics, classification, numerical modeling

INTRODUCTION

Szalai et al. (2002), presented several geometrical null arrays and demonstrated that they are able to localize fissures and to determine their direction. These geometrical null arrays are effective but only in three-dimensional situations. Therefore we started to investigate other geometrical null arrays that could be applied to two-dimensional problems, too. In these new null arrays all electrodes are located along the same measuring line, therefore these arrays will be called “colinear null arrays”. The field implementation of colinear null arrays is easier than that of noncolinear ones for which geometrical adjustments along two axes are needed. Furthermore, these colinear arrays can be routinely integrated in standard 2D multielectrode acquisition procedures.

First we present a classification of all known null arrays. We underline their common features and highlight their various implementations. We then propose a new layout of geometrical null arrays: colinear null arrays. Parameter sensitivity maps, numerical modeling and field tests will demonstrate their effectiveness.

CLASSIFICATION OF GEOELECTRICAL NULL ARRAYS

The null array principle - called by Tarkhov (1957) “methods of pure anomaly” - can be realized in three different ways (Fig. 1): (a) by current focusing, (b) by producing a combined (superposed) parameter from multiple measurements, (c) in a direct way, by a proper geometrical setting. The field setup and the interpretation procedure is the easiest clearly by the geometrical null arrays.
COLINEAR VERSUS NONCOLINEAR GEOMETRICAL NULL ARRAYS

Although null arrays introduced in Szalai et al (2002) were found to be effective for the localization of fissures and the determination of their orientation, they cannot be applied to exactly two-dimensional conductivity distributions. Therefore – motivated by some critical remarks – we searched for other geometrical null arrays that could detect simple two-dimensional heterogeneities. Obviously a colinear geometrical null array – for simple symmetry reasons – would automatically satisfy this criterion. One of the possible colinear null arrays, the midpoint null array (called earlier MAN or single pole array) was studied at first by Tarkhov (1957), but he declared it not very promising. In spite of this opinion after carrying out numerical modeling we have chosen this array for detailed investigations. The other possible more or less simple colinear null array, the Wenner-γ null array is still waiting for detailed investigations. We are going to show that these arrays are able to produce well measurable and geologically meaningful anomalies.

Figure 1. Classification of null arrays. Full (hollow) stars mean source (sink) electrodes. Full circles denote potential electrodes. Numbering (if any) means order of measurements. Current is equally distributed between electrodes A and A’, while A” belongs to another circuit.

NUMERICAL MODELING OF COLINEAR NULL ARRAY ANOMALIES

In order to highlight the main features of colinear midpoint null array anomalies, we carried out numerical simulations. A vertical dyke (akin to wall remnants, see Figure 2), and a vertical contact (Figure 3) were considered. Three different depth values (5 m, 10 m, 15 m) for the anomalous body were considered. The characteristic array lengths were 20 m, 40 m and 60 m. The midpoint null array anomalies are shown together with the conventional Wenner array anomalies. The $k\Delta U/I$ values (where $k$ is the geometric...
coefficient of the conventional Wenner array) give the responses in $\Omega\cdot m$.

Null array anomalies indicate lateral resistivity changes in the subsurface, while conventional array anomalies give the actual resistivity values. In this way the midpoint null array and the conventional Wenner array anomaly curves are complementary. For the vertical contact we should recognize that for all cases (depths 5, 10, and 15 m with array lengths 20, 40 and 60 m) the curves differ from each other only for a scaling factor.

Therefore in Figure 3 all curves are transformed to the case of the depth value of 5m. In Figure 3 it can be seen that the vertical contact is unambiguously marked with the peaks, (at a half array length from the contact toward the resistive side). In Figures 2 and 3 we call the attention to the common $k\Delta U/I$ scale of the conventional Wenner and midpoint null array anomalies. A somewhat surprising fact is that the null array anomalies are comparable in size with anomalies obtained by using conventional arrays.

![Figure 2](image1.png)

**Figure 2.** Numerical modeling results over a 2D dyke. $k$ is geometrical coefficient of the Wenner array. The characteristic array lengths are 20 (+), 40 (●) and 60 m (*).

![Figure 3](image2.png)

**Figure 3.** Numerical modeling results over a vertical contact. $k$ is the geometric coefficient of the Wenner array. Due to the perfect geometrical similarity, the curves can be transformed into one single situation (in our case the depth to the contact is 5 m).

![Figure 4](image3.png)

**Figure 4.** Numerical modeling results over a series of fault steps

- a) by using Wenner array
- b) by using midpoint null array
- c) the model cross section

Another demonstration is shown in Figure 4. The conventional Wenner array gives information only about the main trend in the basement, while the null array anomaly gives information about the individual fault steps. The length of the undulations in the null array anomaly is the same as the length of the fault steps. Moreover, for small array lengths, the minima exactly locate the steps. The apparent resistivity undulations of the conventional anomalies are definitely smaller than the midpoint null array $k\Delta U/I$ values.
FIELD TEST MEASUREMENTS

We illustrate the method with measurements from two field tests shown in Figures 5 and 6. The main result of these tests is that for both field situations it was possible to carry out geologically meaningful measurements with the proposed colinear null array methods: subsurface heterogeneities are located with significant signals, while over quasi-homogeneous regions the colinear null array signals remain consistently very small. Moreover, it was possible to model the most important features of the null array anomalies by using 2D numerical model calculations.

Looking at the cross section of the first field test site (Fig. 5b) and the 2D model (Fig. 5c), it is obvious that there is a good qualitative agreement between the measured (B) and the computed curve (C). The underground garages and a water pipeline were detected, and the responses were satisfactorily verified by numerical modeling.

Another field test was carried out in Finland, about 20 km northwest from Oulu, over a near-surface fault system. The measuring line crosses perpendicularly the contact of the Muhos formation (~200 Ω.m) and the Kiiminki Schist Belt (~1200 Ω.m). The uppermost layer (~500 Ω.m) consists of quaternary till and sand. Based on VLF-R depth estimations an array length of 60 m was selected. Both midpoint null array and Wenner-γ null array measurements were carried out, as well as conventional Wenner measurements. The results for these three arrays are shown correspondingly in Figure 6a, c and b.

Together with the field curves we show the model curves, corresponding to the model geometry by Sharma and Kaikkonen (1998) on basis of VLF measurements. These model curves are presented under the name “start model”. The start model curves are too smooth compared to the field curves. In order to get a better fit between the measured curves and the modeled ones, we decided to add further fault steps to the start model. In the so obtained modified model curves, shown as “modified model” in Figure 6, a reasonably large part of the details in the measured curves are reflected. A perfect agreement between the measured and the modeled curves – due to the complexity of the subsurface – could not be the object of this field test.

Figure 5. Field test over underground garages by using midpoint null array
a) Results of measurements and of the numerical computation
b) Sketch of the vertical cross section of the test site
c) Vertical cross section of the 2D model

d) Cross section of the 2D model

Figure 6. Field measurement at a test site in Finland with a characteristic array length of 60 m
a) by using midpoint null array
b) by using Wenner array
c) by using Wenner-γ null array
d) cross section of the 2D model, with modifications
CONCLUSIONS

In the paper of Szalai et al. (2002) the complementary features of some geometrical null array anomalies in respect of conventional geoelectric anomalies were demonstrated. Some difficulties of those geometrical null arrays oriented us to find further geometrical null arrays that (1) can be applied not only in case of 3D inhomogeneities, (2) their field setup is simple, (3) they can be automatically used in multielectrode systems. As a result of this search we developed colinear null arrays. We recommend two versions: the midpoint null array and Wenner-$\gamma$ quasi-null array.

Parameter sensitivity maps, numerical modeling studies and field tests demonstrate the usefulness of these colinear null arrays. The colinear null array anomalies fulfilled all of our aforementioned expectations. Due to the fact that their geometry is simpler than those of noncolinear null arrays, the physical relationship between the anomalous body and the anomaly itself is also somewhat simpler.

We also call the attention that the colinear null array anomalies are equally well measurable as the conventional geoelectric anomalies. We recommend the midpoint null- and Wenner-$\gamma$ null arrays as a new branch of geoelectrical null array techniques. These colinear geometrical null arrays seem to be more advantageous than the noncolinear ones. They are also easy to implement in the field with standard electrical resistivity tomography measurements.

In the future the interpretation procedures for the null array techniques should be developed.

REFERENCES


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