COMPUTER PROGRAM FOR THE TRANSFORMATION OF VES DATA

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ABSTRACT

A computer program is presented to perform all required ransformations for the inter-
pretation of VES (veitical electrical sounding) data. The program is in BASIC and can be run
on microcomputers. The resistivity transform function is computed from the apparent resistivity
data obtained with four types of electrode array (two-electrode, Wenner, Schlumberger and
dipole-dipole). The program also allows transformation from one sounding curve obtained any
of the above mentioned arrays to others.

The program is mainly based on the least-squares approximation of unequally spaced data.
Moreover, the forward modelling option which uses a modified version cf the linear filter techni-
que for the unequally spaced data is included.

INTRODUCTION

In recent years, tremendous developments have been made in com-
puter technology. Among others, with the advance of personal compu
ters, in–field processing and interpretation of geophysical data have
become possible. Currently, numbers of personal computers employed
by geophysical contractors have been progressively increased. Cor-
respondingly, more software will have to be developed by the user since
the initial cost of the software offered by relevant companies seems to
be expensive for small geophysical contractors, at least in developing
countries. In–house development of software is time–consuming and the
exact cost is hidden. The only way to reduce the expense is to distribute
and exchange software stored on a floppy disk in machine code or to
publish source programs.

The purpose of this paper is to present a computer program which
performs the fundamental transformations required in the interpretation

of vertical electrical sounding (VES) data. Namely, the presented program calculates the resistivity transform function from the VES data or an apparent resistivity model curve for any of the two–electrode, Wenner, Schlumberger, dipole–dipole arrays. The coefficients obtained from the results of above mentioned transformations permit simultaneous calculation of the corresponding VES data in other three electrode configurations. The program stores the output data on a floppy disk. These stored outputs can be used by other interpreting and plotting programs.

Description of the problem

There are three types of fundamental transformation problems in the resistivity sounding method. The first one, the so–called forward modelling, is to convert the resistivity transform function to an apparent resistivity curve for a given electrode array to serve the computation of standard model curves. In order to check the validity of the interpretation, this transformation is also required to compare a field curve with a model curve computed using the parameters derived from the result of interpretation. The comparison of field data with a model curve, the so–called iterative interpretation method, can be made by the computer. The comparison is repeated by changing the layer parameters until a satisfactory agreement between the two sets of data is reached.

The second type of transformation is to convert the apparent resistivity data to Koefoed's (1970) resistivity transform function. This function is related with layer parameters through an algebric relation and is independent of the type of array used for the measurements. The interpretation techniques deriving layer parameters from the resistivity transform data is the so–called "direct interpretation". The first step of direct interpretation is to carry out the transformation which is here named as the second type.

The direct interpretation method is based on the reduction of the resistivity transform curve to a lower boundary plane after the calculation of the top layer parameters (thickness and resistivity) at each step. Some proposed direct interpretation techniques are Pekeris (1940), Koefoed (1970), Szaraniec (1980) and Başokur (1984a).

The third type is the transformation of apparent resistivity data from one electrode configuration into another. The transformation of a apparent resistivity data obtained in one electrode configuration to

Schlumberger data is more important than others, because the avaible computer programs of the iterative interpretation have been mostly prepared for the Schlumberger array.

All above mentioned transformations are performed traditionally by the use of the linear filter method since the pioneering work of Ghosh (1971). The possibility of the application of the convolution theorem for computing resistivity sounding curves has been demonstrated by Kunetz (1966). Many papers tackling the same problem have been published to perfect the method and filter coefficients. Mostly, they have been summarized by Koefoed (1979).

Recently, Santini and Zambrano (1981) developed a numerical method of calculating the resistivity transform data from Schlumberger apparent resistivity data. Their method is based on the approximation of VES data by a linear combination of suitable fitting functions. In the following years, it has been extended to Wenner and an arbitrary electrode configurations by Kumar and Chowdary (1982), Kohlbeck (1985), respectively. Furthermore, the method is also used for the computation of apparent resistivity model curves for Schlumberger, Wenner and two–electrode arrays (Santini and Zambrano 1983). In all papers related to the method, it has been concluded that the method has advantages over the linear filter method since the equally spaced data is no longer necessary. As a result, approximately equally spaced field data can be input to the computer without interpolation. However, in my opinion, the main advantage of the method is that it allows the computation of three types of transformations in a very effective way by using one single computer program while the linear filter tecnique requires separate computations of each transformation for each electrode array.

The presented computer program uses a generalized version of Santini and Zambrano's (1981) method based on the least–squares approximation of VES data. The linear filter technique has been also used to generate VES model curves to test the computer program and to compare the results of the two methods. The computational scheme of the linear filter method has been modified in order to obtain unequally spaced data. This modification increases the computation time, considerably. However, the linear filter technique is omitted in the routine use of the program.

The program presented here has been designed to perform the three types of transformations for the two–electrode, Wenner, Schlumberger

and dipole–dipole electrode arrays. But, it may be easily modified to other electrode arrangements. Figure 1 shows the above mentioned electrode arrays and their electrode spacings used traditionally as abscissa in the presentation of the apparent resistivities.
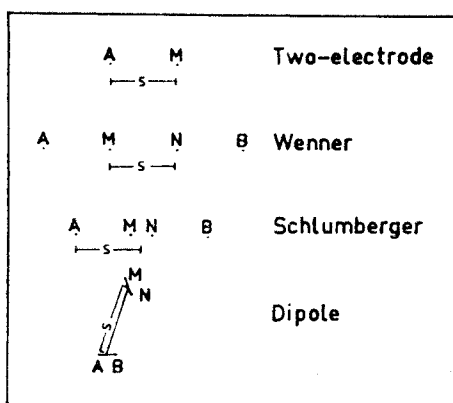

Figure 1. Conventional electrode arrays and corresponding electrode spacings used for the data presentation.

Computations of resistivity sounding curves by the use of linear filter method.

The first step of all computational methods of apparent resistivity model curves is the same, e.i., the computation of the sample values of the resistivity transform function from a given layer parameters depends on the Pekeris recurrence relation (Pekeris 1940, Koefoed 1979). The second step is the computation of sample values of apparent resistivity from the sample values of the resistivity transform function.

For this purpose, different computational techniques have been offered. In the linear filter technique, the convolution of the resistivity transform function with the sinc response (filter coefficients) which differs according to the used electrode array yields the sample values of apparent resistivity. This argument can be expressed as

$$\rho_a(x) = T(x) * [F(x) * P(x)],$$

where $\rho_a(x)$ denotes the apparent resistivity for a given array, x denotes the natural logarithm of electrode spacings shown in Fig. 1, x = ln

$(1 / \lambda)$ for the resistivity transform function $T (\lambda)$. $F (x)$ is the filter function and $P (x)$ is the interpolating function (Başokur 1984 b).

The accuracy of the computation depends on the performance of the selected filter. On the other hand, it is difficult to test several published sets of filter coefficients. For this reason, the choice of a particular set depends on personal experience and available computing facilities. In the presented computer program, the filter coefficients of O'Neill and Merrick (1984) have been used for computing two–electrode and Wenner apparent resistivities and the filters of Murakami et al. (1984) and Koefoed (1979) have been used to compute Schlumberger and dipole–dipole apparent resistivities, respectively.

Transformation of VES data using the least-squares technique

The first step of Santini and Zambroano's (1981) method consists of the approximation of Schlumberger apparent resistivity data by a linear combination of simple fitting functions. The fitting operation is carried out by the least–squares method. Secondly, they construct the Stefanescu kernel function by the linear combination of corresponding fitting functions using the decomposition coefficients of the previous combination.

For the sake of brevity, only the basic theory of the method will be summarized in the following. The reader should refer to the mentioned papers in the manuscript for more details. Here, my main purpose is to show that the determination of the decomposition coefficients for any given array permits the construction of corresponding apparent resistivities in other electrode configurations and the kernel function as long as analytical relations between input and output fitting functions are derived.

Let us to approximate the Stefanescu kernel by a linear combination of suitable fitting functions; $g(\lambda; \varepsilon)$. According to Santini and Zambrano (1982), simple exponential function is the most efficent in fitting the kernel curve:

$$K^* (\lambda) = \sum_{i=1}^{m} b_i \, g (\lambda; \varepsilon_i),$$

where

$$g (\lambda; \varepsilon_i) = \exp (-\varepsilon_i \lambda)$$

and $K^* (\lambda)$ is an approximation of $K(\lambda)$. By defining a new function:

$$y\ (L)\ =\ \frac{\rho_{aL}\ (L)\ -\ \rho_1}{2\ \rho_1}$$

and substituting the kernel function in the two–electrode apparent resistivity expression and finally applying inversion formulas of Hankel transforms, we get

$$y^*(L) = \sum_{i=1}^{m}\ b_i\ f\ (L;\ \varepsilon_i),$$

where

$$f\ (L;\ \varepsilon_i)\ =\ L\ /\ (\varepsilon_i^2\ +\ L^2)^{1/2}$$

The appropriate fitting functions for Wenner, Schlumberger and dipole–dipole arrays may be derived by using existing relationships between apparent resistivity functions of two electrode and one of the other arrays while keeping b_i and ε_i coefficients unchanged. The results are

$$f\ (a;\ \varepsilon_i)\ =\ 2\ a\ /\ (\varepsilon^2_i\ +\ a^2)^{1/2}\ -\ 2\ a\ /\ (\varepsilon^2_i\ +\ 4a^2)^{1/2},$$

$$f\ (s;\ \varepsilon_i)\ =\ s^3\ /\ (\varepsilon^2_i\ +\ s^2)^{3/2},$$

$$f\ (R;\ \varepsilon_i)\ =\ R^3\ (R^2\ +\ (1{-}3p)\ \varepsilon^2_i)\ /\ (\varepsilon_i^2\ +\ R^2)^{5/2}$$

$$=\ \{\ 1\ +\ (1{-}3p)\ (\varepsilon_i\ /\ R)^2\}\ /\ (1\ +\ (\varepsilon_i\ /\ R)^2)^{5/2},$$

where p is a constant defining the type of dipole–dipole configuration. Except the dipole–dipole fitting function, the other ones have been published (Santini and Zambrano 1981, 1983).

The observed VES data should be extrapolated both towards the left and the right up to almost reaching the asymtotes ρ_1 and ρ_n, respectively. The first and last values of ε_i are taken approximately equal to the first abscissae of the apparent resistivity and half of the last abscissae value of the apparent resistivity, respectively. Thus, the number of fitting functions (m) and ε_i values can be calculated by distributing equally spaced five fitting functions over one logarithmic cycle.

The calculation of the number of fitting functions and ε_i values is more complex for the computation of the apparent resistivity model curves. The procedure to compute m and ε_i is well described by Santini and Zambrano (1981, 1983). However, all these computations are carried out automatically by the presented program.

It is obvious from the above equations, if the sample values of a VES field or model curve is known then the corresponding VES data in other electrode arrays and the Stafanescu kernel function (consequently the resistivity transform) can easily be obtained using the same decomposition coefficients.

Case of perfectly insulating and conducting substratum

In the case of a perfectly insulating substratum, the fitting function given above could not show the same behaviour with the apparent resistivity curves and the kernel function, because the VES data will approach an asymptote with a slope of $45°$ at large abscissa values. The set of fitting functions which shows the same property with VES data may be given as:

$$g(\lambda;\varepsilon_i) = \exp(-\varepsilon_i\lambda)\,/\,\varepsilon_i\lambda,$$

$$f(a;\varepsilon_i) = (2a/\varepsilon_i)\,\{\mathrm{Ln}\,[\varepsilon_i + (4a^2 + \varepsilon_i^2)^{1/2}]$$

$$-\,\mathrm{Ln}\,[\varepsilon_i + (a^2 + \varepsilon_i^2)]\},$$

$$f(s;\varepsilon_i) = (s/\varepsilon_i)\,[1-\varepsilon_i/(\varepsilon_i^2 + s^2)^{1/2}],$$

$$f(R;\varepsilon_i) = (R/\varepsilon_i)\,(1-p)\,[1-\varepsilon_i/(\varepsilon_i^2 + R^2)^{1/2}]$$

$$-\,p\,R^3/(\varepsilon_i^2 + R^2)^{3/2}.$$

As can be noted, a fitting function for the two–electrode array is not given since the integral equation for this array does not converge in this case (Santini and Zambrano 1983).

Similarly, for the particular case of conducting substratum, it is necessary to use the fitting functions which tend to zero in the same way as VES data for large abscissa values. These functions may be derived from Santini and Zambrano (1982) as follows:

$$g(\lambda;\varepsilon_i) = 1 - \exp(-\varepsilon_i\lambda),$$

$$f(L;\varepsilon_i) = 1-L/(\varepsilon_i^2 + L^2)^{1/2},$$

$$f(a;\varepsilon_i) = 1 - [2a/(\varepsilon_i^2 + a^2)^{1/2} - 2a/(\varepsilon_i^2 + 4a^2)^{1/2}],$$

$$f(s;\varepsilon_i) = 1 - s^3/(\varepsilon_i^2 + s^2)^{3/2},$$

$$f(R;\varepsilon_i) = 1 - R^3\,(R^2 + (1 - 3c)\varepsilon_i^2)\,/\,(\varepsilon_i^2 + s^2)^{5/2}.$$

Algorithm description and usage

The computer program has been written in Microsoft BASIC (BASICA, version 3.0) and it runs under the DOS operating system and IBM–

PC or compatible microcomputers. In the program, an algorithm which solves a system of simultaneous linear equations with symmetric coefficient matrix has been adapted and converted to BASIC from a FORTRAN IV subroutine "GELS" (reprinted by permission from system / 360 Scientific Subroutine Package (1968) by International Business Machines Corporation).

The statements employed in the computer program are supported both BASIC interpreter and compiler. Execution under interpreter is slow. It is recommended to compile the program and obtain an executable program under the operating system. During the compilation of the program, /E switch should be activated to handle "ON ERROR GOTO" and "RESUME" statments (refer to the Microsoft BASIC compiler user's guide). The minumum memory requirement for the compiler is 64 K.

At the runtime, the program instructs the user and asks only the necessary questions. It also checks inputs and repeats a question until it obtains a reasonable answer. Surely, the sample values of VES data and electrode spacings cannot be checked. The program poses the following questions may be omitted as long as they are unnecessary.

Question 1: "Give data filename or write end". The program asks the caption. It may consist of any number of characters. However, the first eight characters are used as the filename to access the VES data on floppy disk. The first character of the caption shouldn't be numeric. If a file with the same filename already exists on the disk, any existing data in the file will be destroyed and new data will be saved if one answers question 4 positively. If one writes "END" then the program is terminated.

Question 2: "New field data (Y /*)". If the user enters any character except "Y" or "y" then previously stored data on the disk are accessed and are printed on the display. In all cases, the program branches to question 3.

Question 3: "Enter (the key number) spacing and app. res. >". A pair of numbers, electrode spacing and corresponding apparent resistivity value are entered leaving space between each number. The data sets can be given in any order since the data are sorted according to the electrode spacings before proceeding to the next stage. To correct any data entries, the key number, the correct electrode spacing and apparent resistivity values separated by a space are entered. The way to

cancel data entries is similar to the correction procedure. Zero is assigned to the electrode spacing or to the apparent resistivity value. (R) option is choosen to re–initialize the program when the user accidentally access an undesired file. (P) option is used to display the sorted data. (C) or (S) options are choosen to proceed to the next stage while (S) option permits to store the data on the disk under the name given in question 1. The extension "DAT" is automatically added to the filename.

Question 4: At this question, the type of electrode array is declared by entering 1 for the resistivity transform function, 2 for the two–electrode, 3 for Wenner, 4 for Schlumberger and 5 for the dipole–dipole apparent resistivities. If the input is the resistivity transform function the program computes apparent resistivity model curves for electrode arrays which will be declared in question 5.

Question 5: "Give the desired outputs Yes=O". This question enables the user to select outputs. Selection is made by pressing the "RE-TURN" key when the name of any electrode array has appeared. If the user enters a number other than zero, the computations for this array are omitted. Finally, the last question of this session "Correct (Y / *)" allows to correct errors which have been made in questions 4 and 5.

Question 6: At this question, the type of VES data is entered. The options are perfectly conductive substratum (–1), the substratum with finite resistivity (0) and perfectly resistive substratum (1). The resistivity of the top layer is also asked.

Question 7: "Continue (Y /*)". After the above questions have been answered, the program will begin to approximate the input data by fitting functions. The results will be listed on the display together with this question. If the difference between field data and approximated data is very high, the results are not acceptable, and then the user may answer this question negatively. In that case, the program will return to the question 1 and all calculated data will be destroyed. Otherwise, the user enters "Y" and the program produces a hard copy via the line printer.

Question 8: "Store the outputs on floppy disk (Y / *")". This question allows the storing of outputs on the disk. The filenames of outputs are adjusted by keeping the first seven characters of the filename of the input data and by adding one character to the end of it. These added characters are "R" for the resistivity transform function, "T" for two–

electrode array, "W" for Wenner array, "S" for Schlumberger array and "D" for the dipole–dipole array.

After all these questions have been answered, the program computes all desired outputs and produces hard copies via the line printer.

Test mode

In the above, normal usage of the program has been described to transform the VES field data obtained in one electrode configuration to another configuration and to calculate the resistivity transform curve from VES data or to compute apparent resistivity model curves by means of the least–squares technique. To test the performance of the program and accuracy of the method, the test mode is provided. In the test mode, a model curve is generated using the linear filter method and is fed to the computer as an input. For operating the program in the test mode, the first sample value of apparent resistivity is assigned to minus one. Then, the program asks the layer parameters between questions 5 and 6. The sample values of the model curve and the VES data computed by the least - squares method as well as relative errors between data groups will be printed. A small relative error indicates the good performance of the method.

If the input is the resistivity transform function, the calculation of VES model curves in the test mode is made by the use of both the linear filter and least–squares methods. In this case, relative errors on the print-out indicates the relative difference between the two methods.

The program can also be used to obtain the printout of a VES model curve. The type of electrode array is selected in question 4 and the first sample value of apparent resistivity data is assigned to minus one. Question 5 is answered negatively except the electrode array selected in question. 4. Then, the program computes the sample values of a model VES curve by the use of the linear filter technique.

Example

The results of a demonstration run will be presented so that the user can check and edit the program until correct results are obtained.

The first and second columns of Table 1 present electrode spacings and coresponding apparent resistivity values for Schlumberger array for the case where the layer resistivities are 1, 20, 0.1, 1 ohm–m and

Table 1. Schlumberger apparent resistivity data (APR. RES.), approximated data (COM. APR. RES.) and the relative errors between the two sets of data.

SCHLUMBERGER APPARENT RESISTIVITY RESISTIVITY OF THE TOP LAYER IS 1.0 NUMBER OF FITTING FUNCTIONS = 15			
ABSCISSA	APR. RES.	COM.APR.RES	REL. ERROR
3.00000D — 01	1.00672D + 00	1.00659D + 00	−1.26971D — 04
4.00000D — 01	1.01558D + 00	1.01592D + 00	3.37794D — 04
5.00000D — 01	1.02955D + 00	1.02942D + 00	−1.23334D — 04
6.00000D — 01	1.04930D + 00	1.04898D + 00	−3.05703D — 04
8.00000D — 01	1.10743D + 00	1.10766D + 00	2.10162D — 04
1.00000D + 00	1.18991D + 00	1.19013D + 00	1.88195D — 04
1.20000D + 00	1.29297D + 00	1.29286D + 00	−8.28774D — 05
1.60000D + 00	1.54236D + 00	1.54186D + 00	−3.24210D — 04
2.00000D + 00	1.81793D + 00	1.81818D + 00	1.42219D — 04
2.50000D + 00	2.16116D + 00	2.16173D + 00	2.63001D — 04
3.00000D + 00	2.48142D + 00	2.48121D + 00	−8.06526D — 05
4.00000D + 00	3.02498D + 00	3.02404D + 00	−3.08163D — 04
5.00000D + 00	3.43598D + 00	3.43633D + 00	1.03648D — 04
6.00000D + 00	3.72605D + 00	3.72711D + 00	2.83090D — 04
8.00000D + 00	4.00772D + 00	4.00710D + 00	−1.55327D — 04
1.00000D + 01	3.99690D + 00	3.99584D + 00	−2.65567D — 04
1.20000D + 01	3.80141D + 00	3.80203D + 00	1.63172D — 04
1.60000D + 01	3.15957D + 00	3.16122D + 00	5.20145D — 04
2.00000D + 01	2.47618D + 00	2.47509D + 00	−4.41554D — 04
2.50000D + 01	1.78747D + 00	1.78582D + 00	−9.24709D — 04
3.00000D + 01	1.32572D + 00	1.32661D + 00	6.74225D — 04
4.00000D + 01	8.93097D — 01	8.95352D — 01	2.52442D — 03
5.00000D + 01	7.81595D — 01	7.80653D — 01	−1.20453D — 03
6.00000D + 01	7.75037D — 01	7.72922D — 01	−2.72899D — 03
8.00000D + 01	8.19826D — 01	8.20444D — 01	7.53961D — 04
1.00000D + 02	8.60854D — 01	8.62458D — 01	1.86298D — 05
1.20000D + 02	8.90419D — 01	8.90815D — 01	4.45420D — 04
1.60000D + 02	9.27582D — 01	9.26036D — 01	1.66733D — 03
2.00000D + 02	9.48949D — 01	5.47990D — 01	−1.01064D — 03
2.50000D + 02	9.64872D — 01	9.66106D — 01	1.27891D — 03

thicknesses are 1,2, 3 meters. The computation of Schlumberger apparent resistivity was carried out by the linear filter method and the results were stored on disk by using the presented program in the mode described on the last paragraph of the above section. At the second run of the program, these values were fed to the computer as the input simulating a field curve. The approximated apparent resistivity (COM. APR. RES) shown on the third column of Table 1 and relative errors shown on the fourth column were obtained. As the relative errors were small, question was answered affirmatively to let the computer continue the calculation of the outputs. The corresponding outputs, namely the sample values of the resistivity transform function and the apparent resistivities, are presented in Table 2. In daily usage, the VES data of each electrode array are printed on separate pages.

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Table 2. Corresponding apparent resistivities for the resistivity transform function $T^*(1/\lambda)$, the two electrode apparent resistivity $\rho_a^*(L)$, the Wenner apparent resistivity $\rho_a^*(a)$ and the radial dipole apparent resistivity $\rho_a^*(R)$.

ABSCISSA	$T^*(1/\lambda)$	$\rho_a^*(L)$	$\rho_a^*(a)$	$\rho_a^*(R)$
3.00000D — 01	1.00183D + 00	1.34969D + 00	1.01942D + 00	9.94566D—01
4.00000D — 01	1.01178D + 00	1.42673D + 00	1.04331D + 00	9.93915D—01
5.00000D — 01	1.03323D + 00	1.57298D + 00	1.07928D + 00	9.88580D— 01
6.00000D — 01	1.06641D + 00	1.67997D + 00	1.12727D + 00	9.80414D—01
8.00000D — 01	1.16015D + 00	1.88215D + 00	1.25465D + 00	9.65370D—01
1.00000D + 00	1.27763D + 00	2.06669D + 00	1.41352D + 00	9.57087D—01
1.20000D + 00	1.40822D + 00	2.23266D + 00	1.59123D + 00	9.58220D—01
1.60000D + 00	1.68327D + 00	2.50965D + 00	1.96370D + 00	1.00500D+00
2.00000D + 00	1.95282D + 00	2.71985D + 00	2.32107D + 00	1.11911D+00
2.50000D + 00	2.26066D + 00	2.90518D + 00	2.71844D + 00	1.23750D+00
3.00000D + 00	2.52572D + 00	3.02337D + 00	3.05292D + 00	1.56854D+00
4.00000D + 00	2.91706D + 00	3.11863D + 00	3.53991D + 00	2.07051D+01
5.00000D + 00	3.14042D + 00	3.09193D + 00	3.81743D + 00	2.56288D+00
6.00000D + 00	3.23606D + 00	2.99383D + 00	3.93121D + 00	3.02279D+03
8.00000D + 00	3.20008D + 00	2.69736D + 00	3.82882D + 00	3.78008D+00
1.00000D + 01	3.03064D + 00	2.36643D + 00	3.48502D + 00	4.29075D+00
1.20000D + 01	2.82974D + 00	2.05644D + 00	3.05447D + 00	4.57175D+00
1.60000D + 01	2.46407D + 00	1.56590D + 00	2.23425D + 00	4.57244D+00
2.00000D + 01	2.18485D + 00	1.24783D + 00	1.63222D + 00	4.07898D+00
2.50000D + 01	1.93533D + 00	1.02563D + 00	1.17883D + 00	3.21176D+00
3.00000D + 01	1.76032D + 00	9.20278D — 01	9.48150D — 01	2.39865D+00
4.00000D + 01	1.53815D + 00	8.63433D — 01	8.01280D — 01	1.33772D+00
5.00000D + 01	1.40693D + 00	8.72429D — 01	7.98177D — 01	8.82984D—01
6.00000D + 01	1.32225D + 00	8.92405D — 01	8.24130D — 01	7.31420D—01
8.00000D + 01	1.22206D + 00	9.25586D — 01	8.73052D — 01	7.20922D—01
1.00000D + 02	1.16650D + 00	9.46681D — 01	9.04947D — 01	7.76728D—01
1.20000D + 02	1.13210D + 00	9.60681D — 01	9.26368D — 01	8.20564D—01
1.60000D + 02	1.09289D + 00	9.78120D — 01	9.53735D — 01	8.72303D—01
2.00000D + 02	1.07185D + 00	9.88414D — 01	9.70436D — 01	9.03132D—01
2.50000D + 02	1.05661D + 00	9.96262D — 01	9.83478D — 01	9.29811D—01

Remarks

It should be kept in mind that the use of the least–squares method requires more knowledge about the nature of the method than the linear filter method. Accuracy depends on the abscissa range and type of selected fitting functions. On the contrary, to use a computer program based on the linear filter technique, the user should only know the extrapolation of the VES curve is required to the left as well as to the right. For this reason, I recommend the user to refer to previously mentioned papers for a detailed understanding of the method.

Moreover, the program may produce incorrect results in the computation of Wenner apparent resistivity by the linear filter method at large abscissa values for the case where the substratum is perfectly conductive or resistive. A set of Wenner filter coefficients which gives very accurate

```
1  '****************************************************************************
2  '
3  'FILENAME "TRM"
4  '
5  '****************************************************************************
6  'TRANSFORMATION OF VES DATA OBTAINED WITH TWO-ELECTRODE,WENNER,SCHLUMBERGER
   'AND DIPOLE CONFIGURATIONS
7  '
8  'DEVELOPED BY A.T.BASOKUR
9  '
10 '****************************************************************************
11 CLS:KEY OFF:OPTION BASE 1
12 DEFINT I-N:DEFDBL A-H,O-Z
13 DIM S(38),ROA(38),Y(38),E(30),F(30,100),EN(30),ES(465),AUX(30),IPT(5),Z$(5),R
(38),RP(15),T(15),Z(38)
14 '
15 '************************************************************¥£**********
16 '
17 'S(I) ..........ELECTRODE SPACINGS
18 'ROA(I)..........APPARENT RESISTIVITY VALUES
19 'Y$ ..............TITLE
20 'RO1.............RESISTIVITY OF THE TOP LAYER
21 '
22 '****************************************************************************
23 '
24 Z$(1)="RESISTIVITY TRANSFORM FUNCTION":Z$(2)="TWO-ELECTRODE APPARENT RESISTIV
ITY":Z$(3)="WENNER APPARENT RESISTIVITY":Z$(4)="SCHLUMBERGER APPARENT RESISTIVIT
Y":Z$(5)="DIPOLE-DIPOLE APPARENT RESISTIVITY"
25 CLS:LOCATE 1,50:COLOR 0,7:PRINT "Developed by A.T.Basokur":COLOR 7,0
26 '
27 '****************************************************************************
28 'READ TITLE
29 '
30 IMD=0:IMT=0:ALF1=1#:ALF2=1#:LOCATE 9,24:INPUT "GIVE FILENAME OR ENTER END >",
C$:IF C$="" THEN BEEP:GOTO 30
31 '
32 '****************************************************************************
33 'TERMINATE THE PROGRAM IF DESIRED
34 '
35 IF C$="END" OR C$="end" THEN CLS:END
36 'CREATE FILENAME AND ADD FILENAME EXTENSION ".DAT
37 '
38 Y$=LEFT$(C$,8)+".DAT"
39 '
40 'NEW OR STORED FIELD DATA
41 LOCATE 10,29:PRINT "NEW FIELD DATA ? (Y/*)":A$=INPUT$(1):CLS
42 IF A$="Y" OR A$="y" THEN PRINT "NO"SPC(4)"SPACING"SPC(9)"APR.RES.":COLOR 0,7:
LOCATE 1,70:PRINT SPC(1)LEFT$(C$,8)SPC(1):COLOR 7,0:NS=0:GOTO 58
43 '
44 'CHECK WHETHER THE DATA WAS PREVIOUSLY STORED
45 '
46 ON ERROR GOTO 56
47 OPEN "I",#1,Y$
48 FOR I=1 TO 41
49 '
50 'CHECK END OF FILE AND  CALCULATE THE NUMBER OF SAMPLE VALUES
51 IF EOF(1) THEN NS=I-1:CLOSE #1:GOSUB 583:GOTO 58
52 INPUT#1,S(I),ROA(I)
53 NEXT I
54 '
55 'PRINT THE PREVIOUSLY STORED DATA
56 RESUME 57
57 LOCATE 11,20:PRINT "NO DATA WAS FOUND UNDER THE GIVEN FILENAME":LOCATE 20,25:
PRINT "PRESS ANY KEY TO CONTINUE":A$=INPUT$(1):CLS:GOTO 29
58 LOCATE 22,1:PRINT "(S) SAVE and CONTINUE - (C) CONTINUE - (P) SORT and REPRIN
T - (R) RE-INITIALISE";
59 LOCATE 23,1:PRINT "ENTER (THE KEY NUMBER) SPACING and APP.RES. >"SPC(25)::LOC
ATE 23,46:INPUT "",A$:G$=LEFT$(A$,1)
60 IF G$="C" OR G$="c" THEN GOSUB 421:GOTO 86
61 IF G$="R" OR G$="r" THEN GOTO 25
62 IF G$="S" OR G$="s" THEN GOSUB 421:GOSUB 406:GOTO 86
63 IF G$="P" OR G$="p" THEN GOSUB 421:GOSUB 583:GOTO 58
64 I=INSTR(A$," "):IF I<=0 THEN BEEP:GOTO 59
65 A1$=LEFT$(A$,I-1):A$=RIGHT$(A$,LEN(A$)-I)
66 I=INSTR(A$," "):IF I>0 THEN GOTO 73
67 SS=VAL(A1$):RH=VAL(A$)
68 IF SS<=0# OR RH<=0# THEN BEEP:GOTO 59
69 NS=NS+1:IF NS>40 THEN BEEP:NS=40:GOTO 59
70 S(NS)=SS:ROA(NS)=RH:JW=NS:IF JW=21 THEN LOCATE 1,38:PRINT "NO"SPC(4)"SPACING"
SPC(9)"APR.RES"
71 IF JW>20 THEN JQ=38:JK=NS-20 ELSE JQ=1:JK=JW
72 GOTO 81
73 JW=VAL(A1$):JK=JW
74 IF JW<=0 OR JW>40 OR JW>NS+1 THEN BEEP:GOTO 59
75 IF JW=NS+1 THEN NS=NS+1
76 IF JW>20 THEN JQ=38:JK=JW-20 ELSE JQ=1
77 S(JW)=VAL(LEFT$(A$,I-1))
78 ROA(JW)=VAL(RIGHT$(A$,LEN(A$)-I))
79 IF (S(JW)=0# OR ROA(JW)=0#) AND NS=40 THEN NS=NS-1:GOSUB 582:GOTO 58
80 IF S(JW)=0# OR ROA(JW)=0# THEN GOSUB 412:GOSUB 582:GOTO 58
```

```
81 LOCATE JK+1,JQ:PRINT SPC(35):LOCATE JK+1,JQ:PRINT USING "##";JW;:PRINT TAB(JQ
+4)"";:PRINT USING "####.#";S(JW);:PRINT TAB(JQ+20)"";:PRINT USING "####.####";
ROA(JW)
82 GOTO 59
83 '**************************************************************************
84 'SELECT THE TYPE OF ELECTRODE CONFIGURATION
85 '
86 CLS:LOCATE 2,8:PRINT "RES.TRANSFORM=1 TWO ELECTODE=2    WENNER=3   SCHLUMBERGER
=4   DIPOLE-DIPOLE=5"
87 LOCATE 5,25:INPUT "GIVE TYPE OF THE INPUT >",NC:IF NC<1 OR NC>5 THEN BEEP:GOT
O 87
88 '
89 '**************************************************************************
90 'READ THE TYPE OF DIPOLE CONFIGURATION
91 '
92 IF NC=5 THEN LOCATE 6,20:INPUT "GIVE THE TYPE OF DIPOLE CONFIGURATION >",ALF1
:IF ALF1<=0# THEN BEEP:GOTO 92
93 '
94 '**************************************************************************
95 'SELECT THE OUTPUTS WHICH WILL BE CALCULATED
96 '
97 LOCATE 9,25:PRINT "GIVE THE DESIRED OUTPUTS YES=0"
98 LOCATE 10,27:INPUT "RESISTIVITY TRANSFORM  >",IPT(1)
99 LOCATE 11,35:INPUT "TWO-ELECTRODE   >",IPT(2)
100 LOCATE 12,35:INPUT "WENNER         >",IPT(3)
101 LOCATE 13,35:INPUT "SCHLUMBERGER   >",IPT(4)
102 LOCATE 14,35:INPUT "DIPOLE-DIPOLE  >",IPT(5)
103 IF IPT(5)=0 THEN LOCATE 16,20:INPUT "GIVE THE TYPE OF DIPOLE CONFIGURATION >
",ALF2:IF ALF2<=0# THEN BEEP:GOTO 103
104 '
105 '**************************************************************************
106 'ALLOW TO CORRECT ERRORS
107 '
108 LOCATE 22,35:PRINT "CORRECT (Y/*)":A$=INPUT$(1)
109 IF A$="Y" OR A$="y" THEN 114 ELSE GOTO 86
110 '
111 '**************************************************************************
112 'READ THE TYPE OF SUBSTRATUM
113 '
114 CLS:PRINT SPC(30)"CONDUCTIVE SUBSTRATUM=-1"
115 PRINT SPC(30)"FINITE    RESISTIVITY= 0"
116 PRINT SPC(30)"RESISTIVE  SUBSTRATUM= 1"
117 PRINT SPC(30)"GIVE   YOUR   CHOICE   >";:INPUT "",KY:IF KY=-1 OR KY=1 OR KY=0
 THEN GOTO 118 ELSE BEEP:GOTO 114
118 IF NC=2 AND KY=1 THEN CLS:PRINT "THIS METHOD DOSEN'T WORK FOR TWO ELECTORODE
 CONFIGURATION IN CASE OF RESISTIVE SUBSTRATUM":PRINT "PRESS ANY KEY TO CONTINUE
":A$=INPUT$(1):CLS:GOTO 30
119 LOCATE 10,25:INPUT "GIVE RESISTIVITY OF THE TOP LAYER  >",RO1
120 LOCATE 22,35:PRINT "CORRECT (Y/*)":A$=INPUT$(1)
121 IF A$="Y" OR A$="y" THEN 126 ELSE GOTO 114
122 '
123 '**************************************************************************
124 'CHECK THE MODE AND BRANCH THE PROGRAM
125 '
126 CLS:IF NC=1 THEN GOTO 128
127 IF ROA(1)<>-1 THEN GOTO 159
128 IMD=1:GOSUB 434
129 IF NC=1 AND ROA(1)<>-1 THEN IMD=0
130 IF NC=1 THEN GOSUB 539:GOTO 146
131 NK=NC-1:IF NC=5 THEN P=1#/ALF1 ELSE P=0#
132 '
133 '**************************************************************************
134 'READ THE FILTER COEFFICIENTS AND FILTER CHARACTERISTICS
135 '
136 ON NK GOSUB 455,455,470,480
137 '
138 '**************************************************************************
139 'CALCULATE A THEORETICAL APPARENT RESISTIVITY CURVE
140 '
141 GOSUB 487
142 '
143 '**************************************************************************
144 'SAVE THE CALCULATED MODEL APPARENT RESISTIVTY DATA ON FLOPPY DISK
145 '
146 GOSUB 406:IT=0
147 FOR I=1 TO 5
148 IF IPT(I)=0 THEN IT=IT+1
149 NEXT I
150 '
151 '**************************************************************************
152 'PRINT THEORETICAL APPARENT RESISTIVITY DATA
153 '
154 IF IT=1 AND IPT(NC)=0 THEN IMT=1:GOSUB 549:CLS:GOTO 30
155 '
156 '**************************************************************************
157 'COMPUTE y(I) FUNCTION,Y(I)
158 '
159 CLS
160 FOR I=1 TO NS
161 Y(I)=.5##*(ROA(I)-RO1)/RO1
162 NEXT I
```

```
163 '
164 '*****************************************************************************
165 'COMPUTE NUMBER OF FITTING FUNCTIONS,M
166 '
167 IF S(NS)>=100000# THEN SS=S(NS-1) ELSE SS=S(NS)
168 M7=0:IF NC<>1 THEN SS=.5#*SS:DX=.46051701858#:D=EXP(DX):E(1)=S(1)/D:GOTO 177
169 DX=.3837641822#:E(1)=T(1):D=EXP(DX):M7=CINT((LOG(SS)-LOG(S(1)))/DX)+2:IF KY=
-1 THEN M=M7:GOTO 178
170 RQ=0#:RC=0#
171 FOR I=1 TO LAZ-1
172 RQ=RQ+T(I)*RP(I):RC=RC+T(I)/RP(I)
173 NEXT I
174 RE=RQ:RQ=SQR(RQ/RC):RC=SQR(RE*RC)
175 IF KY=1 THEN SS=2#*RC:GOTO 177
176 IF RR<=RQ THEN SS=SS*RR/RQ
177 M=CINT((LOG(SS)-LOG(S(1)))/DX)+2:IF M+2<M7 THEN M=M7
178 IF NS<=M THEN PRINT "NO SUFFICIENT DATA PRESS ANY KEY TO CONTINUE":A$=INPUT$
(1):CLS:GOTO 30
179 '
180 '*****************************************************************************
181 'COMPUTE Ei COEFFICIENTS,EI(I)
182 '
183 FOR I=2 TO M
184 E(I)=D*E(I-1)
185 NEXT I
186 '
187 '*****************************************************************************
188 'COMPUTE f(vj,Ei) FUNCTION,F(I,J) AND nq COEFFICIENTS,E(I)
189 '
190 FOR I=1 TO M
191 T=0#
192 FOR J=1 TO NS
193 ON ERROR GOTO 201
194 P=1#/ALF1:SV1=E(I)/S(J):SV=SV1^2#
195 '
196 '*****************************************************************************
197 'SELECT THE FITTING FUNCTIONS
198 '
199 ON NC GOSUB 366,374,382,390,398
200 GOTO 202
201 RESUME 202
202 T=T+F(I,J)*Y(J)
203 NEXT J
204 EN(I)=T
205 NEXT I
206 '
207 '*****************************************************************************
208 'COMPUTE Sq,r COEFFICIENTS,ES(I)
209 '
210 K=1
211 FOR IR=1 TO M
212 FOR IQ=1 TO IR
213 T=0#
214 FOR J=1 TO NS
215 T=T+F(IQ,J)*F(IR,J)
216 NEXT J
217 ES(K)=T
218 K=K+1
219 NEXT IQ
220 NEXT IR
221 '
222 '*****************************************************************************
223 'COMPUTE bi COEFFICIENTS,EN(I)
224 'SOLVE A SYSTEM OF SIMULTANEOUS LINEAR EQUATIONS WITH SYMMETRIC COEFFICIENT
225 'MATRIX UPPER TRIANGULAR PART OF WHICH IS ASSUMED TO BE STORED COLUMNWISE
226 '
227 'EPS........AN INPUT CONSTANT WHICH IS USED AS RELATIVE TOLERANCE FOR TEST
    ON LOSS OF SIGNIFICANCE
228 '*** REPRINTED BY PERMISSION FROM SYSTEM /360 SCIENTIFIC SUBROUTINE
229 '     PACKAGE (1968) BY INTERNATIONAL BUSINESS MACHINES CORPORATION *********
230 '*****************************************************************************
231 '
232 EPS=.0000001#
233 N=1:IER=0:PIV=0#:L=0
234 FOR K=1 TO M
235 L=L+K:TB=ABS(ES(L))
236 IF TB-PIV<=0# THEN 238
237 PIV=TB:I=L:J=K
238 NEXT K
239 TOL=EPS*PIV:LST=0:NM=N*M:LEND=M-1
240 FOR K=1 TO M
241 IF PIV<=0 THEN 286
242 IF IER<>0 THEN 244
243 IF PIV-TOL<=0 THEN IER=K-1
244 LT=J-K:LST=LST+K:PIVI=1/ES(I)
245 FOR L=K TO NM STEP M
246 LL=L+LT:TB=PIVI*EN(LL):EN(LL)=EN(L):EN(L)=TB
247 NEXT L
248 IF K-M>=0 THEN 272
```

```
249 LR=LST+INT((LT*(K+J-1))/2):LL=LR:L=LST
250 FOR II=K TO LEND
251 L=L+II:LL=LL+1
252 IF L-LR=0 THEN ES(LL)=ES(LST):TB=ES(L):GOTO 255
253 IF L-LR>0 THEN LL=L+LT
254 TB=ES(LL):ES(LL)=ES(L)
255 AUX(II)=TB
256 ES(L)=PIVI*TB
257 NEXT II
258 ES(LST)=LT:PIV=0:LLST=LST:LT=0
259 FOR II=K TO LEND
260 PIVI=-AUX(II):LL=LLST:LT=LT+1
261 FOR LLD=II TO LEND
262 LL=LL+LLD:L=LL+LT
263 ES(L)=ES(L)+PIVI*ES(LL)
264 NEXT LLD
265 LLST=LLST+II:LR=LLST+LT:TB=ABS(ES(LR))
266 IF TB-PIV>0 THEN PIV=TB:I=LR:J=II+1
267 FOR LR=K TO NM STEP M
268 LL=LR+LT:EN(LL)=EN(LL)+PIVI*EN(LR)
269 NEXT LR
270 NEXT II
271 NEXT K
272 IF LEND<0 THEN 286
273 IF LEND=0 THEN 289
274 II=M
275 FOR I=2 TO M
276 LST=LST-II:II=II-1:L=INT(ES(LST)+.5)
277 FOR J=II TO NM STEP M
278 TB=EN(J):LL=J:K=LST
279 FOR LT=II TO LEND
280 LL=LL+1:K=K+LT:TB=TB-ES(K)*EN(LL)
281 NEXT LT
282 K=J+L:EN(J)=EN(K):EN(K)=TB
283 NEXT J
284 NEXT I
285 GOTO 291
286 LOCATE 9,20:PRINT "NO SOLUTION PRESS ANY KEY TO CONTINUE":A$=INPUT$(1):CLS:G
OTO 30
287 '
288 '***************************************************************************
289 'COMPUTE AN APPROXIMATION OF APPARENT RESISTIVITY DATA AND RELATIVE ERROR
290 '
291 FOR J=1 TO NS
292 T=0#
293 FOR I=1 TO M
294 T=T+EN(I)*F(I,J)
295 NEXT I
296 R(J)=RO1*(1#+2#*T)
297 NEXT J
298 '
299 '***************************************************************************
300 'PRINT THE OUTPUTS
301 '
302 GOSUB 549
303 FOR K=1 TO 5
304 NK=K-1
305 IF IPT(K)<>0 THEN 358
306 IF K=2 AND KY=1 THEN 358
307 IF NC<>5 AND K=NC THEN 358
308 '
309 '***************************************************************************
310 'PRINT THE TITLE AND THE TYPE OF ELECTRODE CONFIGURATION VIA LINE PRINTER
311 '
312 LPRINT:LPRINT C$:LPRINT Z$(K)
313 IF K=5 THEN P=1#/ALF2:LPRINT "DIPOLE-DIPOLE CONSTANT =";:LPRINT USING "##.##
##^^^^";ALF2 ELSE P=0#
314 IF IMD=0 THEN 322
315 '
316 '***************************************************************************
317 'COMPUTE THE SAMPLE VALUES OF RESISTIVITY TRANSFORM
318 '
319 IF K=1 THEN GOSUB 539:GOTO 322
320 ON NK GOSUB 455,455,470,480
321 GOSUB 487
322 IF IMD=1 THEN LPRINT " ABSCISSA"SPC(11)"APR.RES."SPC(11)"COM.APR.RES"SPC(8)"
REL.ERROR"; ELSE LPRINT " ABSCISSA"SPC(11)"APR.RES.";
323 FOR J=1 TO NS
324 T=0#
325 FOR I=1 TO M
326 ON ERROR GOTO 334
327 SV1=E(I)/S(J):SV=SV1^2#
328 '
329 '***************************************************************************
330 'SELECT THE SUITABLE FITTING FUNCTION
331 '
332 ON K GOSUB 366,374,382,390,398
333 GOTO 339
334 RESUME 339
335 '
```

```
336 '*********************************************************************
337 'COMPUTE THE SAMPLE VALUES OF APPROXIMATED APPARENT RESISTIVITY DATA
338 '
339 T=T+EN(I)*F(I,J)
340 NEXT I
341 R=RO1*(1#+2#*T)
342 IF IMD=1 THEN 349
343 '
344 '*********************************************************************
345 'PRINT THE RESULTS VIA LINE PRINTER
346 '
347 LPRINT:LPRINT USING "##.#####^^^^";S(J);:LPRINT SPC(7):LPRINT USING "##.####
#^^^^";R;
348 GOTO 350
349 LPRINT:LPRINT USING "##.#####^^^^";S(J);:LPRINT SPC(7):LPRINT USING "##.####
#^^^^";ROA(J);:LPRINT SPC(7):LPRINT USING "##.#####^^^^";R;:LPRINT SPC(7):LPRINT
 USING "##.#####^^^^";R/ROA(J)-1#;
350 ROA(J)=R
351 NEXT J
352 LPRINT CHR$(12);
353 '
354 '*********************************************************************
355 'CREATE OUTPUT FILENAME AND STORE THE OUTPUT ON FLOPPY DISK
356 '
357 IF Q$="Y" OR Q$="y" THEN Y$=LEFT$(C$,7)+LEFT$(Z$(K),1)+".DAT":GOSUB 407
358 NEXT K
359 CLS:GOTO 30
360 '
361 'END OF THE MAIN PROGRAM
362 '*********************************************************************
363 '*********************************************************************
364 'FITTING FUNCTIOS FOR THE RESISTIVITY TRANSFORM
365 '
366 IF KY=-1 THEN F(I,J)=1#-EXP(-SV1)
367 IF KY=0 THEN F(I,J)=EXP(-SV1)
368 IF KY=1 THEN F(I,J)=EXP(-SV1)/SV1
369 RETURN
370 '
371 '*********************************************************************
372 'FITTING FUNCTIONS FOR THE TWO-ELECTRODE ARRAY
373 '
374 IF KY=-1 THEN F(I,J)=1#-1#/SQR(1#+SV)
375 IF KY=0 THEN F(I,J)=1#/SQR(1#+SV)
376 RETURN
377 '*********************************************************************
378 '
379 '*********************************************************************
380 'FITTING FUNCTIONS FOR WENNER ARRAY
381 '
382 IF KY=-1 THEN F(I,J)=1#-2#/SQR(1#+SV)-2#/SQR(4#+SV)
383 IF KY=0 THEN F(I,J)=2#/SQR(1#+SV)-2#/SQR(4#+SV)
384 IF KY=1 THEN F(I,J)=2#*LOG((SV1+SQR(4#+SV))/(SV1+SQR(1#+SV)))/SV1
385 RETURN
386 '
387 '*********************************************************************
388 'FITTING FUNCTIONS FOR SCHLUMBERGER ARRAY
389 '
390 IF KY=-1 THEN F(I,J)=1#-1#/(1#+SV)^1.5#
391 IF KY=0 THEN F(I,J)=1#/(1#+SV)^1.5#
392 IF KY=1 THEN F(I,J)=1#/SV1-1#/SQR(1#+SV)
393 RETURN
394 '
395 '*********************************************************************
396 'FITTING FUNCTIONS FOR DIPOLE ARRAYS
397 '
398 IF KY=-1 THEN F(I,J)=1#-(1#+(1#-3#*P)*SV)/(1#+SV)^2.5#
399 IF KY=0 THEN F(I,J)=(1#+(1#-3#*P)*SV)/(1#+SV)^2.5#
400 IF KY=1 THEN F(I,J)=(1-P)*(1#/SV1-1#/SQR(1#+SV))-P/(1#+SV)^1.5#
401 RETURN
402 '
403 '*********************************************************************
404 'STORE INPUT OR OUTPUT DATA ON FLOPPY DISK
405 '
406 Y$=LEFT$(C$,8)+".DAT"
407 OPEN "O",#1,Y$
408 FOR I=1 TO NS
409 WRITE#1,S(I),ROA(I)
410 NEXT I
411 CLOSE #1:RETURN
412 NS=NS-1
413 FOR I=JW TO NS
414 S(I)=S(I+1):ROA(I)=ROA(I+1)
415 NEXT I
416 S(NS+1)=0#:ROA(NS+1)=0#:RETURN
417 '
418 '*********************************************************************
419 'SORT THE INPUT DATA
420 '
421 CLS
422 FOR I=1 TO NS-1
423 MI=I+1
```

```
424 FOR IJ=MI TO NS
425 IF S(I)<S(IJ) THEN 427
426 SWAP S(I),S(IJ):SWAP ROA(I),ROA(IJ)
427 NEXT IJ
428 NEXT I
429 RETURN
430 '
431 '****************************************************************************
432 'READ LAYER PARAMETERS,RESISTIVITY AND THICKNESS OR DEPTH ·
433 '
434 LOCATE 2,3:PRINT "CHOICE THICKNESS (T) or DEPTH (D)":B1$=INPUT$(1):IF B1$="T
" OR B1$="D" THEN 435 ELSE BEEP:GOTO 434
435 LOCATE 4,3:PRINT " GIVE  NUMBER OF THE LAYER_____>"SPC(3):LOCATE 4,39:IN
PUT "",LAZ:IF LAZ<2 THEN GOTO 434
436 PRINT
437 FOR I=1 TO LAZ-1
438 PRINT
439 PRINT " GIVE RESISTIVITY AND THICKNESS/DEPTH OF THE ";:PRINT USING "##";I;:I
NPUT " TH LAYER >",RP(I),T(I)
440 NEXT I
441 PRINT
442 INPUT " GIVE THE RESISTIVITY OF LAST LAYER_____>",RR
443 LOCATE 22,35:PRINT "CORRECT (Y/*)":A$=INPUT$(1)
444 CLS:IF A$="Y" OR A$="y" THEN GOTO 445 ELSE GOTO 434
445 IF LAZ<3 THEN RETURN
446 IF B1$="T" THEN RETURN
447 FOR I=LAZ-1 TO 2 STEP -1
448 T(I)=T(I)-T(I-1)
449 NEXT I
450 RETURN
451 '
452 '****************************************************************************
453 'FILTERS TO COMPUTE THE SAMPLE VALUES OF APPARENT RESISTIVITY MODEL CURVES
      FOR TWO-ELECTRODE,WENNER,SCHLUMBERGER AND DIPOLE ARRAYS
454 '
455 'IQ (Number of the filter coeficients),II (Number of filter coefficients
     which have positive key number), ZM (Number of the sampling intervals per
     dacade), X (horizontal shift)
456 '
457 '****************************************************************************
458 'Filter coefficients of O'NEILL and MERRICK-Geoph.Prosp.v=30,p=112 for
     computing Two-Electrode or Wenner apparent resistivity model curves
459 '
460 IQ=36:IIF=10:ZM=6#:X=-.046339794#:EE=EXP(2.3025850929#/ZM)
461 Z(1)=-.00040198125#:Z(2)=.0028267073#:Z(3)=-.0126355#:Z(4)=.051125704#:Z(5)=
-.19282817#:Z(6)=.51481121#:Z(7)=-.53249164#:Z(8)=-.32349971#:Z(9)=.1586253#:Z(1
0)=.29934872#
462 Z(11)=.29147621#:Z(12)=.22063809#:Z(13)=.16458964#:Z(14)=.11087382#:Z(15)=.0
80094716#:Z(16)=.05186661#:Z(17)=.037878738#:Z(18)=.023921121#
463 Z(19)=.017713717#:Z(20)=.011157895#:Z(21)=.0060328605#:Z(22)=.0055210545#:Z(
23)=.0032357338#:Z(24)=.0032120792#:Z(25)=.00069159672#:Z(26)=.0024664738#:Z(27)
=-.00082138589#:Z(28)=.0024492093#
464 Z(29)=-.0018292607#:Z(30)=.0026852S8#:Z(31)=-.0024132139#:Z(32)=.0028864314#
:Z(33)=-.0022372433#:Z(34)=.0018339484#:Z(35)=-.C010087715#:Z(36)=.00039053314#
465 RETURN
466 '
467 '****************************************************************************
468 'Filter coefficients of MURAKAMI for computing Schlumberger apparent
     resistivity model curves
469 '
470 IQ=28:IIF=19:ZM=6#:X=.13072093866#:EE=EXP(2.3025850929#/ZM)
471 Z(1)=.000086463368#:Z(2)=-.00036875438#:Z(3)=.00092111524#:Z(4)=-.0018772686
#:Z(5)=.0035343506#:Z(6)=-.0064612278#:Z(7)=.011691267#:Z(8)=-.021088677#
472 Z(9)=.038045092#:Z(10)=-.068913866#:Z(11)=.12665755#:Z(12)=-.2435547#:Z(13)=
.52117305#:Z(14)=-1.2644217#:Z(15)=2.7992503#:Z(16)=-3.4853734#
473 Z(17)=.41912647#:Z(18)=1.1950174#:Z(19)=.6107326#:Z(20)=.24298434#:Z(21)=.08
2207576#:Z(22)=.027770876#:Z(23)=.0087075202#:Z(24)=.0028615354#
474 Z(25)=.00088399812#:Z(26)=.00028020133#:Z(27)=.00010060054#:Z(28)=.00C034147
278#
475 RETURN
476 '
477 '****************************************************************************
478 'Filter coefficients of KOEFOED Geosounding Principles Elsevier 1979 p=97
     for computing Dipole-Dipole apparent resistivity model curves
479 '
480 IQ=30:IIF=17:ZM=6#:X=.1C51#:EE=EXP(2.3025850929#/ZM)
481 Z(1)=-.001#-P*.001#:Z(2)=.0061#+P*.0082#:Z(3)=-.0182#-P*.0346#:Z(4)=.0381#+P
*.1018#:Z(5)=-.0643#-P*.2404#:Z(6)=.0935#+P*.4915#:Z(7)=-.1223#-P*.915#:Z(8)=.14
72#+P*1.6079#:Z(9)=-.1607#-P*2.7371#:Z(10)=.1368#+P*4.5747#:Z(11)=.0298#-P*7.351
4#
482 Z(12)=-.6949#+P*9.9485#:Z(13)=2.3397#-P*6.7406#:Z(14)=-3.4031#-P*6.8271#:Z(1
5)=.5326#+P*15.1421#:Z(16)=1.3371#-P*7.172#:Z(17)=.2972#+P*2.686#:Z(18)=.6032#-P
*3.2828#:Z(19)=-.388#+P*1.5391#:Z(20)=.5669#-P*1.1701#:Z(21)=-.5859#+P*.5929#
483 Z(22)=.6107#-P*.2915#:Z(23)=-.5724#+P*.0642#:Z(24)=.4921#+P*.0563#:Z(25)=-.3
79#-P*.1093#:Z(26)=.2575#+P*.1096#:Z(27)=-.149#-P*.0809#:Z(28)=.069#+P*.0443#:Z(
29)=-.0226#-P*.0164#:Z(30)=.0038#+P*.003#
484 RETURN
485 '
486 '****************************************************************************
487 'COMPUTE THE SAMPLE VALUES OF THE APPARENT RESISTIVITY MODEL CURVE
488 '
```

```
489 FOR J=1 TO NS
490 UU=S(J):GOSUB 510:ROA(J)=RL
491 IF NK<>2 THEN GOTO 493
492 UU=2##S(J):GOSUB 510:ROA(J)=2##ROA(J)-R'
493 NEXT J
494 RETURN
495 '
496 '*********************************************************************
497 'PRINT LAYER PARAMETERS VIA LINE PRINTER
498 '
499 LPRINT "INPUT MODEL"
500 LPRINT "LAYER"SPC(12)"RESISTIVITY"SPC(5)"THICKNESS"SPC(7)"DEPTH"
501 LPRINT SPC(1);"1";TAB(18);"";:LPRINT USING "##.#####^^^^";RP(1);:LPRINT TAB(
34);"";:LPRINT USING "##.####^^^^";T(1);:LPRINT TAB(50);"";:LPRINT USING "##.###
#^^^^";T(1):TT=T(1)
502 FOR LL=2 TO LAZ-1
503 TT=TT+T(LL)
504 LPRINT USING "##";LL;:LPRINT TAB(18);"";:LPRINT USING "##.#####^^^^";RP(LL);
:LPRINT TAB(34);"";:LPRINT USING "##.####^^^^";T(LL);:LPRINT TAB(50);"";:LPRINT
USING "##.####^^^^";TT
505 NEXT LL
506 LPRINT USING "##";LAZ;:LPRINT TAB(18);"";:LPRINT USING "##.#####^^^^";RR:LPR
INT
507 RETURN
508 '
509 '*********************************************************************
510 'Compute a sample value of apparent resistivity
511 '
512 U=UU*EXP(-IIF*2.3025850929#/ZM-X):RL=0#
513 FOR I=1 TO IQ
514 GOSUB 521
515 RL=RL+V*Z(I)
516 U=U*EE
517 NEXT I
518 RETURN
519 '
520 '*********************************************************************
521 'Compute a sample value of the resistivity transform
522 '
523 V=RR:IW=LAZ
524 IW=IW-1
525 D=V
526 C=V/RP(IW)
527 IF C>1# THEN AC=1#/C
528 IF C<1# THEN AC=C
529 AF=LOG((1#+AC)/(1#-AC))/2#
530 AA=T(IW)/U+AF
531 IF ABS(AA)>5# THEN DD=1#:GOTO 534
532 BB=EXP(AA):CC=EXP(-AA)
533 DD=(BB-CC)/(BB+CC)
534 IF C>1# THEN V=RP(IW)/DD
535 IF C<1# THEN V=RP(IW)*DD
536 IF IW>1 THEN 524 ELSE RETURN
537 '
538 '*********************************************************************
539 'Compute the sample values of resistivity transform model curve
540 '
541 FOR J=1 TO NS
542 U=S(J):GOSUB 521:ROA(J)=V
543 NEXT J
544 RETURN
545 '
546 '*********************************************************************
547 'PRINT THE INPUT APPARENT RESISTIVITY DATA AND ITS APPROXIMATION
548 '
549 I=1
550 FOR J=1 TO NS
551 IF I<>1 THEN GOTO 553 ELSE CLS
552 IF IMT=0 THEN PRINT " ABSCISSA"SPC(11)"APR.RES."SPC(11)"COM.APR.RES"SPC(8)"R
EL.ERROR" ELSE PRINT " ABSCISSA"SPC(11)"APR.RES."
553 IF IMT=0 THEN PRINT USING "##.#####^^^^";S(J);:PRINT SPC(7):PRINT USING "##.
#####^^^^";ROA(J);:PRINT SPC(7):PRINT USING "##.#####^^^^";R(J);:PRINT SPC(7):PR
INT USING "##.#####^^^^";R(J)/ROA(J)-1#
554 IF IMT=1 THEN PRINT USING "##.#####^^^^";S(J);:PRINT SPC(7):PRINT USING "##.
#####^^^^";ROA(J)
555 I=I+1
556 IF I=20 THEN LOCATE 23,25:PRINT "PRESS ANY KEY TO CONTINUE":A$=INPUT$(1):I=1
557 NEXT J
558 LOCATE 22,25:PRINT "CONTINUE (Y/*)":A$=INPUT$(1)
559 IF A$="Y" OR A$="y" THEN 560 ELSE CLS:RETURN 30
560 LOCATE 23,15:PRINT "STORE THE OUTPUTS ON FLOPPY DISK (Y/*)":Q$=INPUT$(1)
561 '
562 '*********************************************************************
563 'PRINT THE INPUT APPARENT RESISTIVITY DATA AND ITS APPROXIMATION VIA LINE
     PRINTER
564 '
565 'CHECK THE PRINTER
566 '
567 CLS:ON ERROR GOTO 569
568 LPRINT CHR$(27);CHR$(67);CHR$(0);CHR$(11);:GOTO 571
```

```
569 RESUME 570
570 CLS:BEEP:LOCATE 10,24:PRINT "BE SURE THAT PRINTER IS ON-PRESS ANY KEY TO CON
TINUE":A$=INPUT$(1):CLS:GOTO 568
571 LPRINT:LPRINT C$:LPRINT Z$(NC)
572 IF IMD=1 OR NC=1 THEN GOSUB 499 ELSE LPRINT "RESISTIVITY OF THE TOP LAYER IS
";:LPRINT USING "##.####^^^^";RO1
573 IF IMT=0 THEN LPRINT "NUMBER OF FITTING FUNCTIONS=";M
574 IF NC=5 THEN LPRINT "DIPOLE-DIPOLE CONSTANT =";:LPRINT USING "##.#####^^^^";
ALF1
575 LPRINT:IF IMT=0 THEN LPRINT " ABSCISSA"SPC(11)"APR.RES."SPC(11)"COM.APR.RES"
SPC(8)"REL.ERROR"; ELSE LPRINT " ABSCISSA"SPC(11)"APR.RES."SPC(11);
576 FOR J=1 TO NS
577 LPRINT
578 IF IMT=0 THEN LPRINT USING "##.#####^^^^";S(J);:LPRINT SPC(7):LPRINT USING "
##.#####^^^^";ROA(J);:LPRINT SPC(7):LPRINT USING "##.#####^^^^";R(J);:LPRINT SPC
(7):LPRINT USING "##.#####^^^^";R(J)/ROA(J)-1#;
579 IF IMT=1 THEN LPRINT USING "##.#####^^^^";S(J);:LPRINT SPC(7):LPRINT USING "
##.#####^^^^";ROA(J);
580 NEXT J
581 LPRINT CHR$(12);:RETURN
582 'PRINT THE INPUT DATA
583 CLS:PRINT "NO"SPC(4)"SPACING"SPC(9)"APR.RES.":COLOR 0,7:LOCATE 1,70:PRINT SP
C(1)LEFT$(C$,8)SPC(1):COLOR 7,0
584 JW=2:JQ=1
585 FOR I=1 TO NS
586 LOCATE JW,JQ:PRINT USING "##";I;:PRINT TAB(JQ+4)"";:PRINT USING "####.#";S(I
);:PRINT TAB(JQ+20)"";:PRINT USING "#####.####";ROA(I)
587 IF JW<>21 THEN 590
588 LOCATE 1,38:PRINT "NO"SPC(4)"SPACING"SPC(9)"APR.RES."
589 JW=1:JQ=38
590 JW=JW+1
591 NEXT I
592 RETURN
```

results has not been published till now. For this reason the two–electrode filter has been used and a sample value of Wenner apparent resistivity model curve was obtained from two sample values of two–electrode apparent resistivity (Das and Verma 1980).

Conclusion

A computer program listed in the Appendix has been presented to carry out three types of transformation of VES data by the least–squares method and to compute VES model curves by the linear filter method. The program has been developed for four electrode configurations (two–electrode, Wenner, Schlumberger and dipole–dipole configurations). However, any other array may be included into the program. Field data and outputs can be stored on disk for further processes, e.g. plotting the curves, direct or iterative interpretations and so on.

The program can be run on IBM–PC compatible microcomputers and permits in–field processing of VES data demonstrated by an example.

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