Transmitter waveform and receiver transfer function modelling in time domain induced polarization

Esben Auken
Associate prof.
HydroGeophysics Group
Aarhus University,
Denmark
esben.auken@geo.au.dk

Gianluca Fiandaca
Post doc, guest researcher at Aarhus University
University of Palermo
Italy
gianluca.fiandaca@unipa.it

SUMMARY

In the computation of the forward response for Time Domain Induced Polarization the incomplete description of the transmitter waveform causes dramatic errors in the estimation of the magnitude and time characteristic of the IP phenomenon. Both the duration of the current pulse and the sequence of pulses used for the stacking procedure have a strong effect in the magnitude and shape of the IP decays. Furthermore, it is important to model low-pass filters of the receiver system, in order to extract all the information contained in the acquired data. For these reasons, a new 1D forward and inversion algorithms have been developed using the full time decay of the IP response and the receiver transfer function to reconstruct the distribution of the four Cole-Cole parameters of the earth. The waveform implementation in the forward response for TDIP is a significant improvement that allows moving from a qualitative interpretation of TDIP data for recognition of anomaly patterns towards a quantitative analysis, able to discriminate soil lithotypes and, if present, some contamination plumes.

Key words: Time domain, IP, waveform, filter, inversion

INTRODUCTION

During the last decade the scope of Time Domain Induced Polarization (TDIP) has considerably broadened from mineral exploration to environmental geophysics, mainly for mapping clays and for landfill characterization. Furthermore, modern instruments allow multi-channel acquisition of IP data with multi-core cables and steel electrodes. Therefore, for TDIP surveys the acquisition time is shorter and the logistic is simpler when compared to Spectral Induced Polarization (SIP) surveys (measuring the IP signal in the frequency domin).

While many developments have been made in the instrumentation and acquisition techniques, the inversion schemes commonly used are still not using all the benefits of these improvements: TDIP data are usually inverted using integral chargeability (Oldenburg and Li 1994), without considering the actual transmitter pulse and the system transfer function of the receiver. More importantly, the spectral information in the TDIP data is lost when using integral chargeability only. More recently, other approaches have been presented, that use the entire IP decays instead of the integral chargeability. They invert the time gates independently with DC algorithms (Hönig and Tezkan 2007). But, also in this case, the shape of the transmitter pulse and the receiver transfer function are not considered and the implied approximation is valid only for low values of chargeability (Hördt et al. 2006). Morevover, the incomplete description of the transmitter waveform causes dramatic errors in the estimation of the magnitude and time characteristic of the IP phenomenon, as clearly shown when studying the variability of the TDIP response to an infinite train of current pulses by changing the pulse duration (Tombs 1981).

For these reasons, a new 1D forward algorithm has been developed to reconstruct the full time decay of the IP response taking into account both the transmitter waveform and the receiver transfer function. In the implemented forward response the chargeability phenomenon is modelled in terms of the Cole-Cole parameters (Pelton et al. 1978).

The algorithm has been implemented in the 1D-Lateral constrained Inversion scheme (Auken et al. 2005), in order to reconstruct 2D sections of the subsoil. Field examples from Denmark show an important improvement in the resolution of the parameters that controls the IP-response as compared to traditional integral chargeability inversion.

METHOD AND RESULTS

The step response arising from the turn-off of an infinite current pulse is computed by means of the Fast Hankel Tranforms (Johansen and Sørensen 1979) of the 1D frequency domain response for a layered half-space. The 1D frequency domain forward response is calculated by recurrence relations in terms of the thicknesses and complex impedances of the layers (Koefoed 1979). The frequency impedance $\zeta_j(\omega)$ of the j^{th} layer is expressed by the Cole-Cole formulation:

$$\zeta_j(\omega) = \rho_j \left[1 - \frac{m_{0j}}{10^3} \left(1 - \frac{1}{1 + (i\omega\tau_j)^{C_j}} \right) \right]$$

where ρ_j represents the DC resistivity, m_0 is the intrinsic chargeability as defined in Seigel (1959) in mV/V, τ is the mean relaxation time in seconds and C (dimension-less) controls the width of the distribution of the relaxation times.

The forward response is computed by modelling the full current waveform (a sequence of positive and negative pulses) by superposition of step responses. Stacking is actually needed in the field for noise reduction and self potential removal, and the finite number of pulses has to be modelled to obtain accurate time decays. Figure 1 shows the effect of using the full waveform for a homogeneous half-space, by comparing the step response with the result of six alternating pulses of finite duration.

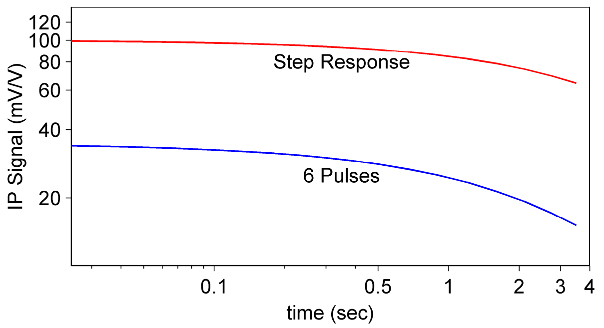

Figure 1 Comparison between the step response (red) and the stacking of six alternating pulses of finite duration (blue) for a homogeneous half space, the parameters being: m_0 = 100 mV/V; τ = 10 sec; C = 0.8; Pulses On-Time = 4 sec; Pulses Off-Time = 4 sec. Note that the left axis is logarithmic.

In order to reduce the noise content, low-pass filters are often present in the TDIP receivers. For the Syscal Pro (Iris Instruments) this filter is close to being a 10 Hz, 6 poled Gaussian filter. The effect of this filter is very pronounced in the first 100 ms of the response and it is necessary to model it to avoid the rejection of the early time gates. Figure 2 shows the effect of filter implementation on the forward response.

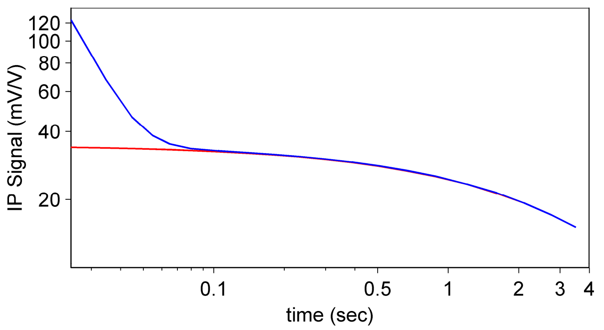

Figure 2 Red line - forward response without the filter implementation; blue line - forward response with the filter implementation. The decays have been computed for the homogeneous halfspace described by the Cole-Cole parameters {m_0=100 mV/V, τ=10 sec, C=0.8} The on- and off-times used for the waveform are: Ton = Toff = 4 sec, with six stacks. The filter is a low-pass 10Hz, 6 poled Gaussian filter.

INVERSION

The forward response has been implemented in the 1D Laterally Constrained Inversion scheme (1D-LCI), producing laterally smooth model sections of the subsurface (Auken et al, 2005). The data space includes the full chargeability decay curves, together with the resistivity values. The 1D model space contains the four Cole-Cole parameters (ρ, m_0, τ and C) and the thickness for each. In a smooth model setup the layers' thicknesses are fixed. Figure 3 presents a synthetic model (red lines) and the corresponding inversion model (blue lines) for a Schlumberger VES. 20 quadrapoles with 20 time gates have been simulated; 3% and 10% Gaussian noises have been added to resistivity and chargeability values, respectively. In figure 3 the dotted blue lines show the confidence intervals for the inversion model (68% probability): all the Cole-Cole parameters of the synthetic model can be resolved, with uncertainty comprised between 10% and 30% of the parameters values.

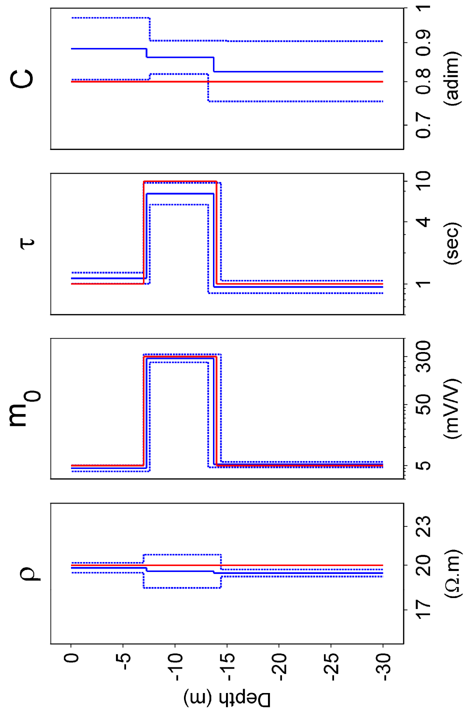

Figure 3 Synthetic model (red lines) and inversion model (continuous blue lines), together with 68% confidence intervals (dashed blue lines). 20 quadrapoles in Schlumberger configuration have been simulated, with 20 time gates per quadrapole. 3% and 10% Gaussian noises have been added to resistivity and chargeability data, respectively.

In field examples from Denmark we have seen promising results in terms of resolving the Cole-Cole parameters and thereby increasing the information on the factors controlling the IP-responses. Examples will be shown in the presentation.

CONCLUSIONS

The waveform implementation in the forward response for TDIP is a significant improvement that allows moving from a qualitative interpretation of TDIP data for recognition of anomaly patterns towards a quantitative analysis, able to discriminate soil lithotypes and, if present, some contamination patterns.

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