2D time domain spectral polarization inversion - full wave modelling and Cole-Cole parameterization

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Field-based time domain induced polarization (TDIP) surveys are usually modelled by taking into account the integral chargeability only, thus disregarding spectral content. Furthermore, the effect of the transmitted waveform is commonly neglected, biasing inversion results. Given these limitations of conventional approaches, a new 2D inversion algorithm has been developed using the full voltage decay of the induced polarization response, together with an accurate description of the transmitter waveform and receiver transfer function. This allows reconstruction of the spectral information contained in the time domain decay series.

The new inversion algorithm is based around a 2D complex conductivity kernel that is computed over a range of frequencies and converted to the time domain through a fast Hankel transform. The same time-domain (TD) transform is applied to both the frequency-domain (FD) forward response and Jacobian, which in frequency-domain is computed through the adjoint method. The model space is defined in term of Cole-Cole parameters (Cole and Cole 1941), the most widely used in literature for describing the polarization phenomenon.

The effects of the current waveform, stacking procedure and (eventual) instrumental filters are modelled following Fiandaca et al. (2012), but using a 2D implementation for the frequency domain kernels.

The duration of a current pulse transmitted by TDIP equipment is typically shorter than the time it takes for an IP signal to fully decay. This means that the pulse response obtained is actually a superposition of two time-shifted step responses. Due to this, the pulse response has smaller amplitude and decays faster than a step response. Stacking measurements, which is normal procedure to reduce noise content, can be expressed as a series of superimposed step responses (Fig. 1a). This averages different decays and therefore the number of stacks used for a given measurement can heavily affect the resulting signal. The typical stacked signal can differ from a single step response by 60–400 % (Fig. 1b). The receiver transfer function can also highly influence the measured data. TDIP meters, such as the IRIS Syscal Pro, have a digital filter implemented to reduce noise. This has the unwanted effect of distorting the IP signal at early times (Fig. 1c); these early time data should be rejected without proper modelling of the filter characteristics (Fig. 1e).

Several factors are involved in ensuring minimal computation time of the inversion algorithm, and therefore its applicability:

(1) Fast computation of the TD Jacobian, by using a fast Hankel transform of the FD Jacobian
(2) Parallel calculation is used for computing FD forward responses and Jacobians at different frequencies, as well as for the time-transformation of the FD kernels.

These features ensure fast computations, with the inversion time being comparable with that of dc algorithms.

With this new algorithm, field-based time domain induced polarization measurements give access to the spectral content of the polarization processes, opening up new applications in environmental and hydrogeophysical investigations.

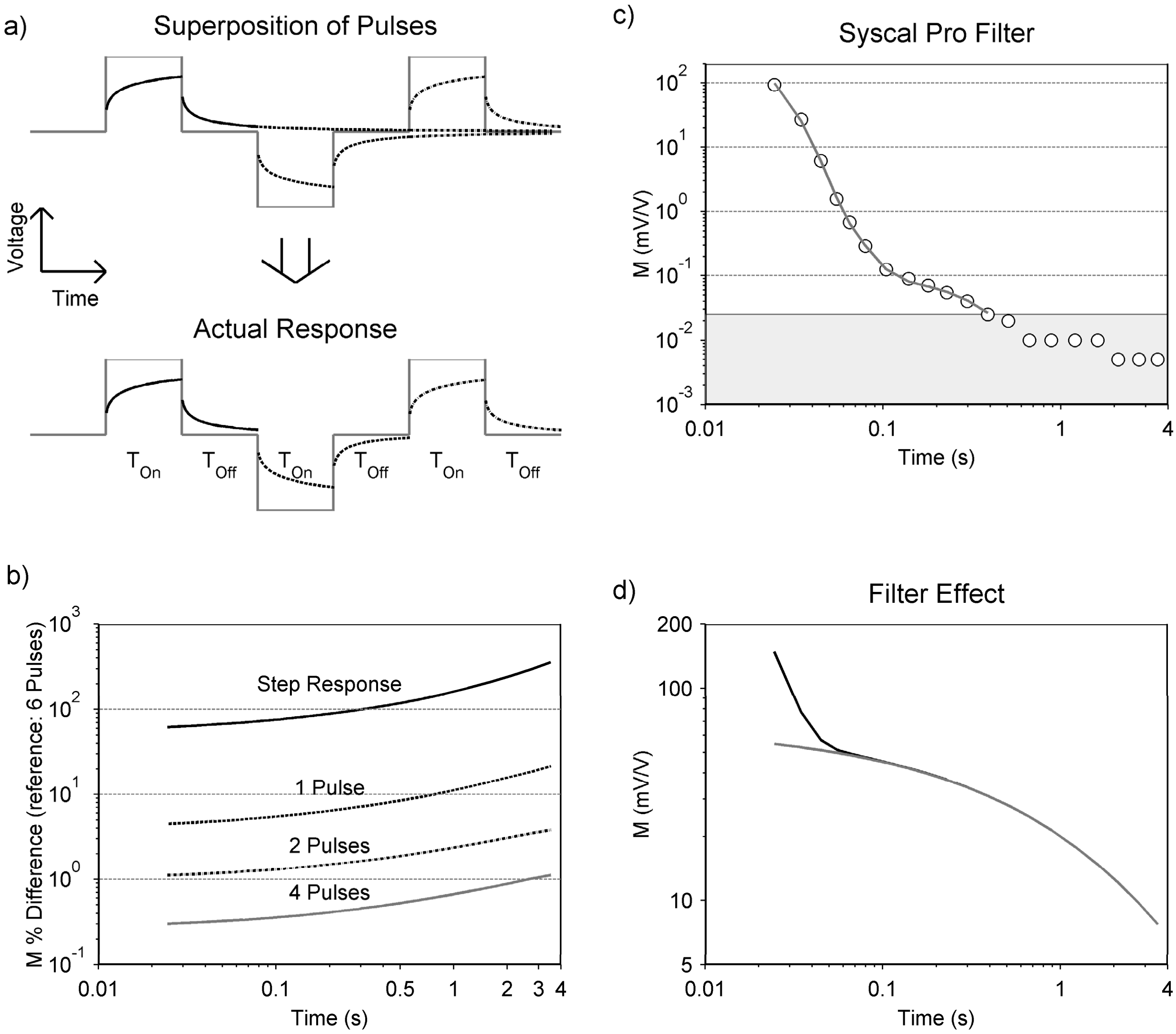

Fig. 1: (a) Construction of the pulse response by superimposing two-step responses; (b) IP percentage difference between decays with different number of stacks (a decay stacked six times is used as a reference) for the homogeneous half-space described by the Cole–Cole parameters ($m_0 = 100\ mV\ V^{-1}$, $\tau = 2\ s$, $c = 0.5$). Solid black line, step response; dashed line, 1 pulse; dotted-dashed line, 2 pulses; grey solid line, 4 pulses. The on- and off-times used for the waveform are: $T_{on} = T_{off} = 4\ s$. Note that the percent axis is logarithmic. (c) IRIS Syscal Pro filter effect (circles) measured in the time domain on a non-chargeable resistor. The grey line represents the modelling of the filter, for which the measurements in the grey rectangle have not been taken into account (because the limit of the digitization of the data has been reached). (d) Example of forward response with the filter implementation (black line) and without the filter implementation (grey line).

References

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