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Shallow information from high magnetic moment measurements

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SUMMARY

Airborne transient electromagnetic measurements obtained with high magnetic moment transmitters are typically not optimal for resolving the near-surface resistivity distribution; however, a number of recent developments in SkyTEM transmitter technology has led to significant improvements in our high moment early time performance. Experimental data, including high and low moment measurements, have been recorded at high altitude and at production level. Using the low moment data as benchmark, we analyse the high moment early time data to determine if we are able to get comparable resolution of the shallow resistivity structure.

Key words: TEM, High magnetic moment, Early time data, Near surface, SkyTEM

INTRODUCTION

The transient electromagnetic measurement aims at recovering the unbiased and noise free response of the subsurface over as wide a time range as possible. Unfortunately, for any one instrument, there is an inherent trade-off between being able to recover the very early response and being able to recover the very late response due to a number of practical limitations. For typical airborne TEM instruments, the relevant time range spans the interval from a few microseconds to many milliseconds.

Because transmitters with high magnetic moments are prevalent in the airborne EM industry, we consider the difficulties encountered when attempting to extract the very early response from measurements made with such high magnetic moments.

One problem relates to achieving a stable waveform to less than a microsecond accuracy.

High magnetic moment transmitters typically transmit large currents into multi-turn conducting loops. The turn-off of such high currents is usually controlled by limiting the turn-off voltage, thereby increasing the turn-off time while avoiding destructively high voltages. When the conducting loops experience a change in temperature their electrical resistance changes along with the peak transmitted current.

The combination of a time varying peak current and a voltage-limited current turn-off typically results in a time varying end-of-ramp for the current waveform and a non-linear relationship between the peak current and the transmitted current waveform.

Furthermore, when the current turn-off is nearly complete and the transmitter voltage drops below the voltage control limit, the free decay of the remaining current commences. This process depends on the resonance frequency of the transmitter system, which again depends on the electrical system parameters of inductance, capacitance and damping resistance. For a large multi-turn transmitter loop the free decay may last long compared to the microsecond time scale responses that are of interest. In addition, the electrical system parameters may vary in time and depend on external environmental factors, introducing further uncertainty to the exact timing of the end-of-ramp.

Another problem relates to the bandwidth of the transmitting and receiving system.

Hodges and Chen (2015) demonstrate the importance of incorporating high frequency excitation in the transmitted current waveform, in order to obtain high amplitude early time responses. Specifically, they show how rapid and more step-like current turn-off shapes are superior to smoother and more prolonged turn-off shapes for recovering responses from short time constant targets. In their analysis, Hodges and Chen (2015) state that they assume that the receiver electronic bandwidth is wide enough as to effectively not be a limiting factor for the combined system bandwidth. We do not generally consider this to be the case. Limiting the receiver bandwidth allows for increased receiver sensitivity, lower sample density required for representing the measured signal and smaller signal dynamic range while passing though less external noise. For these reasons, there is a strong incentive to reduce the receiver bandwidth as much as possible; however, reducing the bandwidth will also result in a significant deterioration of the receiver system high frequency signal representation (Rasmussen *et al.*, 2017).

A final and related problem is that of measurement bias.

The bias phenomena experienced in airborne TEM generally relate to the transmission of the primary field and its interaction with the aircraft, carrier frame and instrumentation. The bias phenomena most influencing the early time earth responses are those characterised by having high amplitude but short off-time duration. The most obvious of these is the direct magnetic coupling of the primary field with the receiver coil. Due to the aforementioned bandwidth limitation of the receiver system, the primary field may influence the recorded data at times significantly later than the actual end-of-ramp for the transmitted waveform. Considering a description in terms of the system response as used by Andersen *et al*. (2015), the direct primary field coupling will result in a primary field bias for as long as there is a non-zero system response. Other main sources of early time bias are those arising from internal eddy currents in the conducting transmitter loops, as well as those arising in systems using active bucking of the primary field, where the cancellation performance may be highly frequency dependent.

SKYTEM HP TRANSMITTERS

A design goal for the ongoing SkyTEM transmitter developments has been to improve the early time performance of high magnetic moment measurements. One of the major results is that the latest generation of transmitters, the SkyTEM HP (High Power) transmitters, are constructed based on a novel transmitter design, which utilises a number of parallel transmitter sections instead of the traditional single transmitter section. This yields advantages in relation to both the transmitter resonance frequency, the achievable turn-on and turn-off voltages and the ability to maintain precision control of the transmitted waveform. Specifically for the SkyTEM306HP system, the ability to ramp up and ramp down the current in each of the six transmitter loop turns separately results in an exceedingly high transmitter resonance frequency.

Further steps taken to reduce early time bias include special in-house manufactured transmitter cabling with negligible internal eddy currents and the use of receiver coil zero positioning instead of primary magnetic field bucking. The main advantage of using zero positioning over bucking, when recording early time data, is that the field geometry of the primary magnetic field is essentially frequency independent. This means that zero positioning works equally well for minimizing the primary field influence at early and late times, whereas a bucking field is challenging to maintain exactly in opposing phase to the primary field over a wide frequency band.

In order to evaluate the early time performance of the 500,000 Am^2 SkyTEM306HP high moment, experimental data were recorded using the new SkyTEM digital receiver, while transmitting both high and low moments at great height and at the Lyngby Test Site in Denmark. The applied Z directed receiver coil has a resonance frequency of 210 kHz and the system anti-alias filter is set to 1 MHz.

A system response for the high moment was derived based on an analysis of the high altitude measurements. By integrating the system response in time, we get a response shape proportional to the transmitted waveform convolved by all system filters, as shown in Figure 1. Because the filters in the system have very high bandwidth, the resulting shape is very close to that of the transmitted waveform.

The high moment system response has the critical property that it scales linearly with the transmitted peak current. This means that the end-of-ramp timing does not change and the current waveform shape is preserved despite variations in peak transmitted current. These properties are achieved by dynamically scaling the transmitter turn-off voltage to follow the peak transmitted current.

The free decay part of the waveform is very rapid, as can be inferred from the bottom panel in Figure 1. This is due to the high transmitter resonance frequency, which enables the recording of undisturbed earth response data very close to the transition between the linear and the exponential part of the current turn-off.

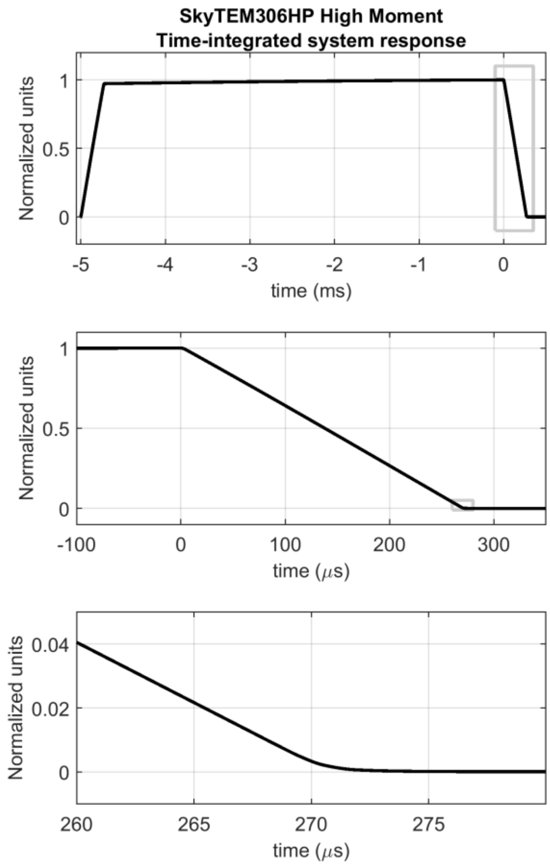

Figure 1. Time-integrated high moment system response for the SkyTEM306HP system. The three panels show different levels of detail. Note the change in horizontal units between the top and middle panel.

COMPARING HIGH AND LOW MOMENT

It would be practical to be able to compare the recorded early time high moment and low moment responses directly in data space. Unfortunately, as discussed by Sørensen and Nyboe (2012), the earth response immediately following a long linear turn-off ramp exhibits step-response characteristics over a time scale proportional to the duration of the ramp. At later times the response gradually transitions to resemble the impulse response. Due to the rapid current turn-off of the low moment waveform, the measured low moment responses are essentially impulse responses.

A somewhat ad-hoc way of comparing the two response types is therefore to numerically differentiate the high moment response and compare it to the low moment response over the time interval during which we may expect the high moment data to behave as a step response. We have performed this analysis and it has shown very promising results. Some examples are shown in Figure 2.

In the presentation we will show further comparisons of the recorded early time high- and low moment responses in both data space and as separately inverted sections demonstrating their respective resolution of the near surface resistivity distribution.

CONCLUSIONS

The development goal of improving the early time performance of our high magnetic moment transmitter has clearly been met with the SkyTEM306HP system. Further testing will determine whether the significant improvements in high moment early time performance may be enough to render the recording of traditional low moment data redundant in a range of geological scenarios.

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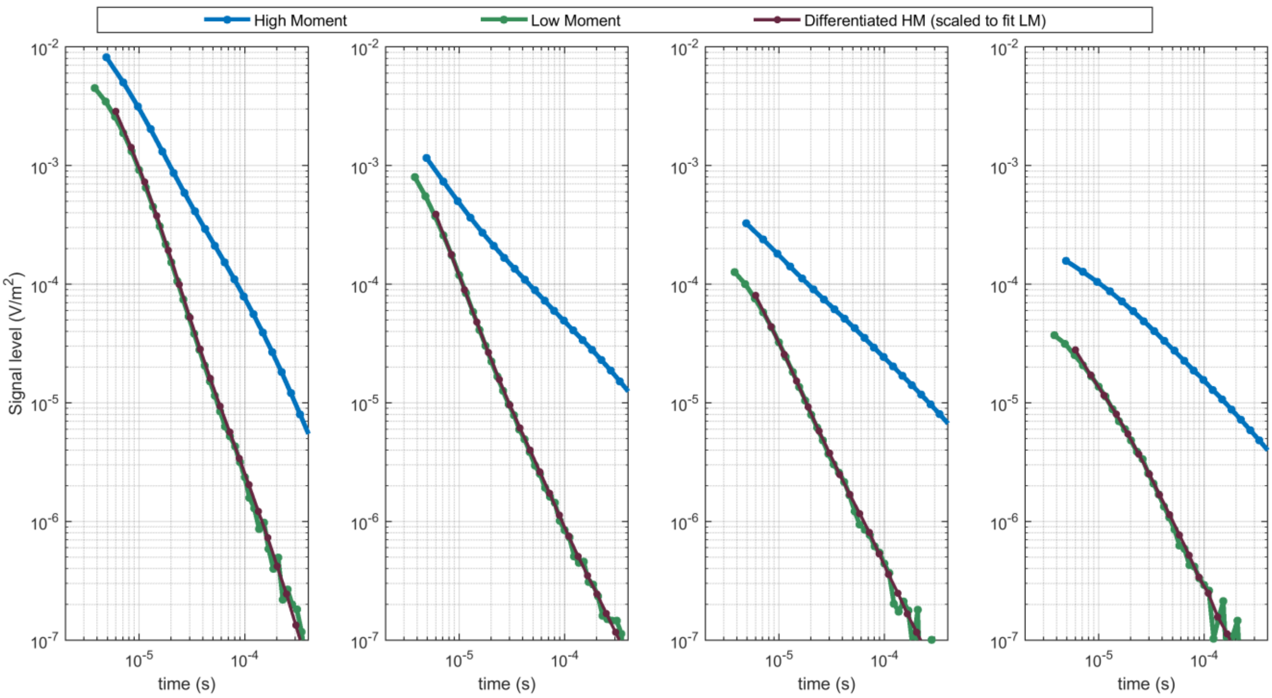

Figure 2. Experimental high- and low moment early time data from the SkyTEM306HP system. The numerically differentiated high moment data curves have been scaled by a common factor to match the low moment data level.