Extending Geobandwidth using the Multipulse Configuration

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SUMMARY

Measurement bandwidth is an important feature of a geophysical system. Bandwidth allows detection of very resistive features (such as some kimberlites) and very conductive targets (like massive sulphides). In electromagnetic systems, bandwidth is not simply the sample rate of the data acquisition system or the earliest time channel, but also depends on transmitter spectrum, distance to target and processing. Optimising a system to detect a feature or measure a specific signal requires design considerations and trade-offs for different targets. The choice of excitation waveform in electromagnetic systems is one such trade-off. A square-pulse allows high-frequency energy to be excited, but, because of electronic limitations, has only limited dipole moment. A half-sine waveform efficiently generates energy at the base frequency and first few odd harmonics (low-frequency energy) and less high-frequency energy. Here, we describe the Multipulse configuration, an option on the Helitem system which employs both a half-sine and a trapezoid waveform to efficiently generate high- and low-frequency energy. Using survey data, we show the resolution power of the combined system compared to a single waveform. The combined data is better able to resolve near-surface features and deep structure than data from either waveform alone.

Key words: bandwidth, near-surface resolution, depth of exploration, Geobandwidth

INTRODUCTION

The measurement bandwidth of a measurement system is extremely important when considering the range of responses that can be detected by the system. For geophysical systems measuring physical fields proportional to conductivity, values of interest range from very resistive (crystalline rocks >10,000 ohm-m) to very conductive (massive sulphides, < 1e-6 ohm-m). Calculating the system nomogram provides an effective visualization of the response to a particular target with a range of electrical properties. Grant and West (1965) showed the response of a frequency domain system to a wire loop conductor as:

$$\frac{E_{CR}}{E_{TR}} = \frac{M_{CR}M_{TC}}{-M_{TR}} \frac{1}{L_C} \frac{Q^2 + iQ}{Q^2 + 1} \tag{1}$$

where the receiver conductor response E_{CR} (normalised by the primary field at the receiver, E_{TR}) depends on the mutual inductance between transmitter and conductor (M_{TC}) and mutual inductance between conductor and receiver (M_{CR}) normalised by coupling between transmitter and receiver (M_{TR}), as well as the wire loop self-inductance L_C and electrical properties of the loop, which are contained in the factor Q ($Q = 2\pi f\ \tau$), where f is the transmitter frequency and $\tau = L_C/R_C$ is the time constant of the loop, and R_C is the loop resistance. Grant and West (1965) show the nomogram for the in-phase and quadrature components. The quadrature response peaks when Q=1, that is, when

$$\tau = {}^{1}/_{2\pi f} \tag{2}$$

To optimise detection of a target with a particular time constant, we can compute the optimal transmitter frequency with this equation.

We can perform a similar exercise for time domain systems by transforming equation (1) to the time-domain. Grant and West give the voltage in a receiver coil from a step-off transmitter current waveform due to a wire loop as:

$$V_{step}(t) = \frac{M_{TC}M_{CR}}{L_c} I_0 \frac{1}{\tau} e^{-t/\tau} \tag{3}$$

Where I_0 is the transmitter current and t is the measurement time after the end of the pulse. For a particular time channel, we can graph the response for a range of time constants and determine which time constant gives the largest response for that channel (Hodges and Chen, 2015). An effective frequency for this time channel can be computed by re-arranging equation (2). Hodges and

Chen (2015) provide the voltage response of a receiver coil for a number of common waveforms and their analytic effective frequency.

Modern time-domain airborne electromagnetic (AEM) systems allow some degree of optimisation in terms of power, base frequency, pulse width and waveform (which at least partially determines timing of the first receiver channel). All of these factors (as well as altitude or distance) determine the strength of the response from the target. We can compare different system configurations (and their respective waveforms, channel times, transmitter power, and transmitter-receiver geometry) by computing their nomogram for a particular target. Doing this allows us to compare the relative sensitivity of the various configurations and determine the range of targets they are sensitive to, that is, their Geobandwidth.

The Multipulse configuration (Chen et al, 2015) employs two waveforms: a high-power half-sine waveform for depth of exploration and a fast-turn off trapezoid waveform for near-surface resolution (Chen et al, 2015). Combining data from both waveforms extends the measurement bandwidth of the system. In this work, we compute the Geobandwidth of the Multipulse configuration. We then show the approximate depth of exploration for early and late times for each waveform. We then provide a data example of Multipulse from two surveys to illustrate the advantages of combining both waveforms into a single system.

METHOD AND RESULTS

The Multipulse configuration of Helitem usually operates (when in 30 Hz base frequency) with a 4 ms half-sine waveform with 10.5 ms of off-time, and a 1 ms trapezoid waveform with 40 µs ramps and 1 ms of measuring time; 50 channels of data are provided, 30 for the half-sine and 20 for the trapezoid pulse. The Geobandwidth of the Multipulse configuration for a wire loop conductor has been calculated and is shown in Figure 1. The first channel of the trapezoid waveform has maximum sensitivity for a wire loop with time constant of 30 µs while the half-sine has maximum sensitivity to a 400 µs time constant. For a channel 1 ms after the pulse, the trapezoid has peak sensitivity to a 0.7 ms time constant, while the half-sine has peak sensitivity to a 1.5 ms time constant. The amplitude for the half-sine pulse is five times larger 1 ms after the end of the pulse than for the trapezoid waveform.

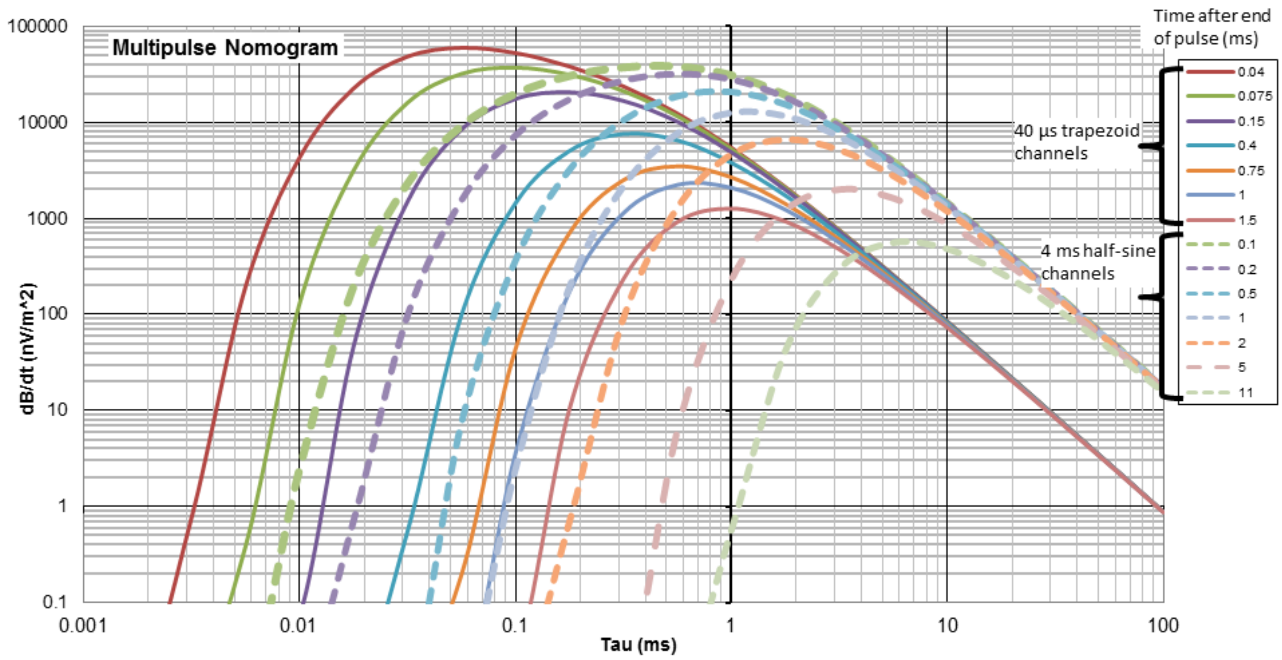

Figure 1: Geobandwidth of a wire loop conductor for a 40 µs turn-off trapezoid and a 4 ms half-sine pulse. The measurement times are given as time after the end of the pulse. The figure shows relative time constant sensitivity and amplitudes for the trapezoid and half-sine waveforms.

Now we compare the depth of exploration of each waveform by first determining the equivalent frequency of each time channel and estimating depth by using the skin depth. This is a simple comparison to give a sense of depth of exploration. For each channel, the time constant giving the peak response is located using Figure 1; the equivalent frequency is computed using equation (2); and the depth of exploration is estimated as $0.7\,\delta$, where the skin depth $\delta=(2\rho/\mu\omega)^{1/2}$. The estimated depth is shown in Figure 2. With a higher equivalent frequency, the channels of the trapezoid pulse have a smaller depth of exploration and are thus able to provide better near-surface resolution. The half-sine channels have smaller equivalent frequencies and larger depth of penetration.

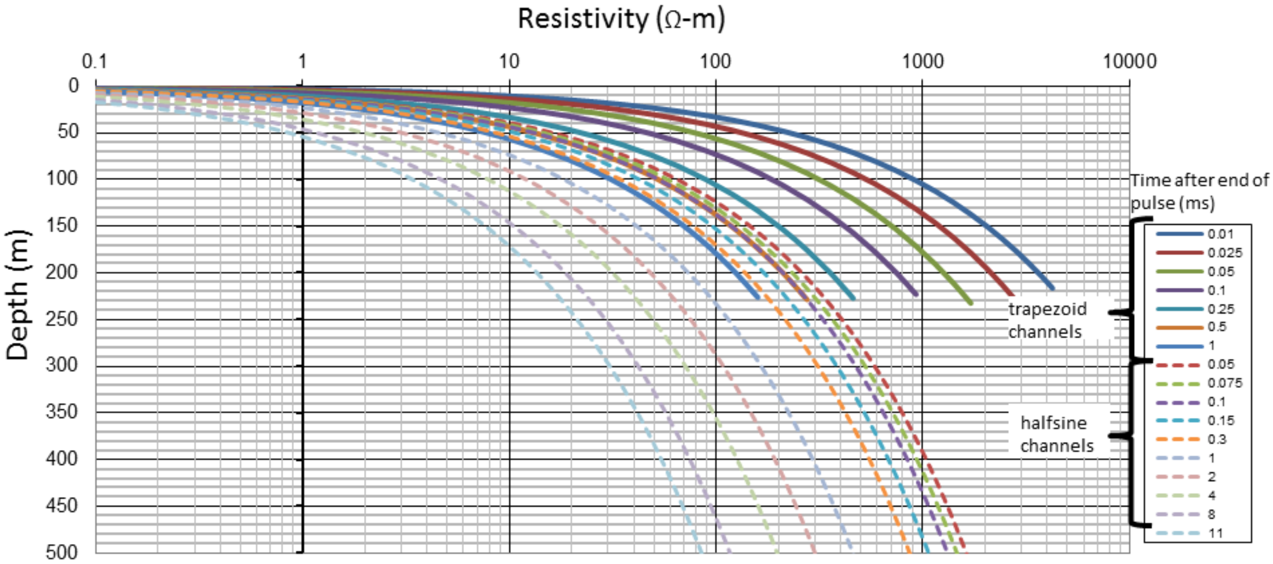

Figure 2: Maximum depth of exploration for each time channel of the trapezoid pulse (solid lines) and half-sine pulse (dashed lines). Maximum depth is estimated as 0.7 times the skin depth.

SURVEY EXAMPLE

Here we show a data example from a Helitem with Multipulse survey flown in South America. In this configuration, the waveform was a 4 ms, 800,000 Am^2 half-sine with a 1 ms, 40,000 Am^2 trapezoid pulse.. The receiver is concentric with the transmitter and flown with a nominal height of 30 m. Figure 3 shows profile data for the half-sine and trapezoid pulse (top) as well as Differential Resistivity™ (Huang and Fraser, 1996) for each pulse (bottom). The Differential Resistivity section from the trapezoid pulse not only shows more detail in the near-surface, but, since it is able to measure earlier in time, is also able to map conductivity at shallower depths. The half-sine pulse has a greater depth of exploration and the section shows features at depth that the trapezoid section does not. The greater depth of exploration is a result of higher power, longer measurement time, and, importantly, the low-frequency energy generated by the half-sine pulse.

CONCLUSIONS

Waveform shape can be used to extend the bandwidth of an EM system. We have used the system response to a particular target to visualise the Geobandwidth of a system; the Geobandwidth shows the relative sensitivity and the range of targets that the EM system is able to detect. A trapezoid waveform and a half-sine waveform have a bandwidth to wire loop conductors that varies by an order of magnitude in terms of time constant. By computing an effective frequency, we can approximate the depth of exploration and contrast the two waveforms: the trapezoid waveform should provide better near-surface resolution while the half-sine has the ability to explore deeper. A data example from South America shows the difference in resolving power between the two waveforms. The trapezoid pulse allowed conductivity information to be extracted from shallower depths than from the half-sine waveform. A conductivity section created from the trapezoid data showed information from at shallower depths and with better resolution. The conductivity section created from the half-sine data showed features at depth not present in the trapezoid conductivity section.

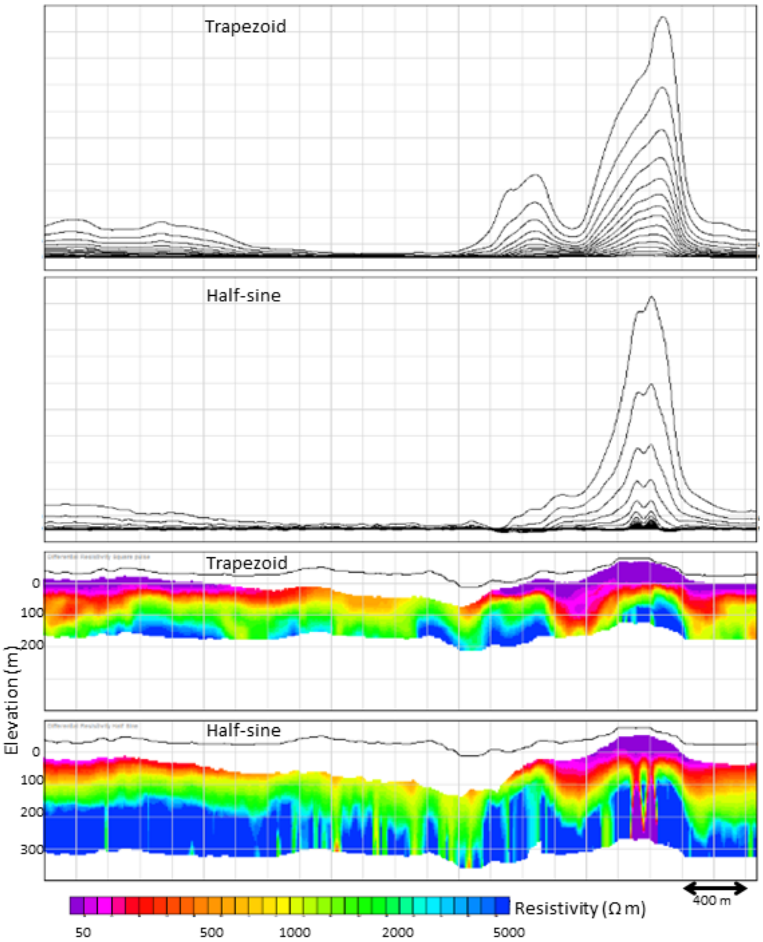

Figure 3: Data from the trapezoid pulse (top panel), half-sine pulse (second panel) and the Differential Resistivity sections from trapezoid (third panel) and half-sine (bottom). Only a hint of a vertical conductor at in the anomaly at the right side of the profile can be seen in the late time data from the trapezoid waveform, while the response is clear in the half-sine data. The Differential Resistivity section created from the trapezoid data has much better near surface resolution and able to see shallower information. The half-sine section is better able to detect deep features.

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