Low-Base Frequency Helicopter AEM Data from a Square-Wave System - Helitem^2

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SUMMARY

Exploration for targets at depth or targets obscured by conductive overburden have historically been a challenge with airborne EM methods. Although modern systems have been improved with greater primary transmitter moments, noise from receiver coil motion in the Earth's ambient field limits detection of secondary target signals, especially in late time. The new Helitem² system uses a patented low-noise receiver and a 50% duty cycle square pulse transmitter waveform to achieve increased signal detectability for deep and covered targets.

A series of demonstration surveys were conducted by surveying a known target to compare several helicopter-borne time-domain system configurations. Despite having a larger dipole moment, a half sine pulse at standard 30 Hz base frequency was predicted to have lower responses than low base frequency (15 Hz and 7.5 Hz) square pulse operation in a thin-plate nomogram over a wide range of target conductances. At early times, the sharper (quicker) turn off of the square wave results in much more high-frequency energy and therefore better signal for weakly conductive targets and better near-surface resolution. At the other extreme, the response from very conductive targets is determined by the area under the transmitter curve, so the low frequency square waves with 16 and 33 ms widths should produce more than twice the signal as the half sine. Survey line profiles and decay curves over the target and background locations confirmed these predictions for a 400 m deep target and variable overburden.

The combination of pulse width, power, and low noise enabled the system to be effective at low base frequencies, where very late time data is beneficial for detecting strong and deep targets.

Key words: time-domain, electromagnetic, low base frequency

INTRODUCTION

Mineral exploration expenditure has not led to a proportional increase in ore discoveries. As the easy-to-find mineral deposits close to the surface have largely been discovered since the routine use of geochemistry and geophysics, explorers must now search for more challenging targets. This includes targets at depth, under conductive cover, or in more difficult exploration areas. In some cases, identifying more subtle resistive features may be beneficial to the exploration process. To aid in both of these cases, CGG has developed the Helitem Squared system, which employs a square-pulse waveform and is capable of operating at frequencies from 6.25 Hz to 30 Hz.

Historically, airborne electromagnetic methods (AEM) have not been as effective as desired for exploring at great depth. Until the 1990's, only relatively small transmitter moments were possible. Long stacking of fast-moving AEM systems has not typically been performed to decrease noise levels because stacking data for long periods in a moving system results in an unacceptable loss of spatial resolution. However, modern systems have greatly increased transmitter moments allowing for greater depth of penetration. Sufficient improvements in receiver design to take advantage of this greater power have been elusive to date but are shown here to now be displaying significant progress at drastically reducing noise levels.

Exploration under conductive cover has different challenges; cover delays the response from the target to later times. With thick cover, the target response may not be detected during the brief off-time of the typical 30 Hz base frequency used by AEM systems, necessitating use of a lower base frequency. However, at low base frequencies the motion of the receiver coil through the static magnetic field of the earth induces signals much greater than the desired target signal (Annan, 1984; Lane et al., 1998). Removing the coil motion noise via post-processing has thus far proven ineffective (Macnae, 2007). The Helitem^2 system has a patented receiver coil suspension system which has drastically reduced the receiver oscillation frequency, reducing coil motion noise and allowing low base frequency surveying. The Helitem^2 system has acquired low frequency 6.25/7.5 Hz, 12.5/15 Hz and 25/30 Hz data on a number of commercial surveys. The waveforms used for 50 Hz mains countries is shown in Figure 1, note the 4-times wider pulse for the 6.25 Hz waveform.

A square pulse waveform is effective for both resistive and conductive targets. For resistive targets, a very fast turn-off maximises high-frequency energy and response from the target, resulting in large secondary signals. We show the importance of turn-off time for resistive targets and near-surface resolution.

As shown by Liu (1998) for very conductive targets, response is proportional to area under the transmitter curve; moment and pulse width combined are important. The Helitem^2 system is able to use a 50% duty cycle square wave, resulting in pulse widths of 10, 20 and 40 ms (at base frequencies of 25, 12.5 and 6.25 Hz) with a moment of 680,000 Am^2. The ability to generate these wide pulses is important for very conductive targets where a doubling of pulse width doubles the response from the target. This paper describes a series of tests and commercial surveys using 30 Hz and lower base frequencies, including 7.5 Hz and 15 Hz. At the time of writing this paper, only moderately conductive (300 S) targets have been flown, but even here the benefit of a wide pulse is evident.

FIELD TEST

A series of field tests have been flown to test system performance at low base frequencies of 7.5 Hz and 15 Hz, compared to a previously flown half-sine waveform at a 30 Hz base frequency (in a 60 Hz power line environment), as well as the effect of pulse width and shape on target detection. Figure 2 shows the waveforms used for the different configurations in the various test flights. The test with the 6 ms half-sine pulse has a much larger moment (factor of 1.5) compared to the square pulses. Even with a lower moment, the induction into the ground is actually higher for the square pulses than the higher-moment half-sine. The 7.5 Hz base frequency allows for a much longer off-time; in this case, the last channel centre time is at 30 ms, compared to about 10 ms for the 30 Hz base frequency, which can provide more information about depth.

Figure 3 shows the thin-plate nomogram for the waveforms depicted in Figure 2. For weakly-conductive targets (small conductance) the square-waves have much higher response than the half-sine. This is because the turn-off time for the square waves is much faster than the half-sine pulse, resulting in much more high-frequency energy. On surveys, this results in much higher secondary signals and better near-surface resolution.

As mentioned by Liu (1998), the response from very conductive targets is determined by the area under the transmitter curve. This is shown in Figure 3 at high conductance values where the 7.5 Hz waveform (33.3 ms pulse-width) has the highest response; about double that of the 15 Hz (16.6 ms pulse-width) response at the highest conductance and considerably higher than the half-sine pulse. Even though the square-pulses have a lower transmitter dipole moment, they have a significantly higher response for these very conductive targets.

We conducted a small survey in a resistive region with relatively thin, moderately conductive cover (about 50 ohm-m, 0-100 m thick) with known sulphide mineralization at depth. Figure 4 compares the response from the 6 ms half-sine waveform and the 33.33 ms (7.5 Hz) square pulse at early time (28 us after pulse-end; this is the first channel of the half-sine and 3rd channel of the square data) and at late time over a deep (400 m) 300 S target (with some moderately-conductive disseminated sulphide around it). The early-time response shows the variable nature of the overburden.

The right-side of Figure 4 shows the late-time response (channels 3 ms after the end-of-pulse). The general features identified by both waveforms are the same, with approximately the same signal levels. The target of interest is located at about 1,700 m; the peak is better defined by the 7.5 Hz square pulse. Figure 5 shows the transient decay measured by each waveform over the anomaly at 1,700 m and a background transient from 300 m away from the anomaly. The response from the 7.5 Hz square pulse is significantly higher in amplitude than from the half-sine, consistent with the prediction at 300 S from the nomogram in Figure 3. This extra amplitude would make detection of this target at even greater depth possible. Most importantly, even at 7.5 Hz operation, there is no increase in coil motion noise.

CONCLUSIONS

We have shown some results from low base frequency surveying from the Helitem^2 AEM system. The surveys showed that the redesigned suspension system was able to mitigate coil motion noise such that low base frequency data is not at all detrimental to detection of deep targets. Without this re-design, noise levels would increase dramatically because of coil motion noise. The 7.5 Hz data provided useful information at very late time. The wide-pulse waveform was effective at energizing a moderately-conductive target, increasing signal level by a factor of 2 above a 6 ms pulse. This will be even more beneficial when exploring for strong conductive targets at depth.

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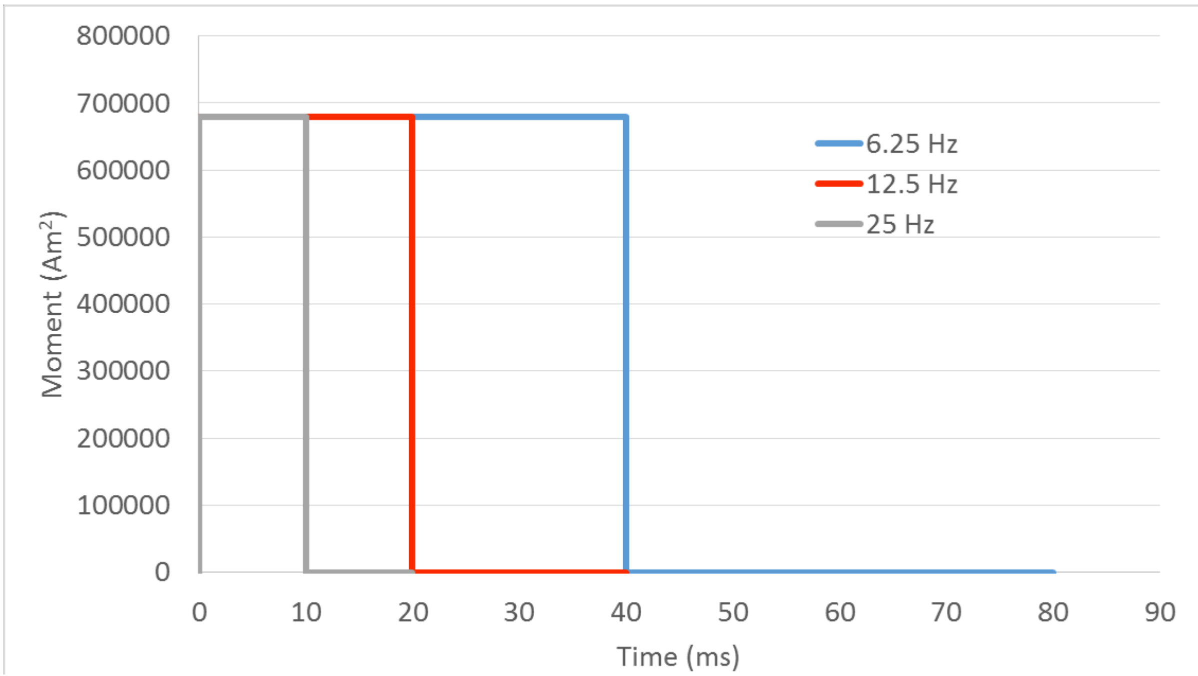

Figure 1. 50% duty cycle waveforms for at 25, 12.5 and 6.25 Hz.

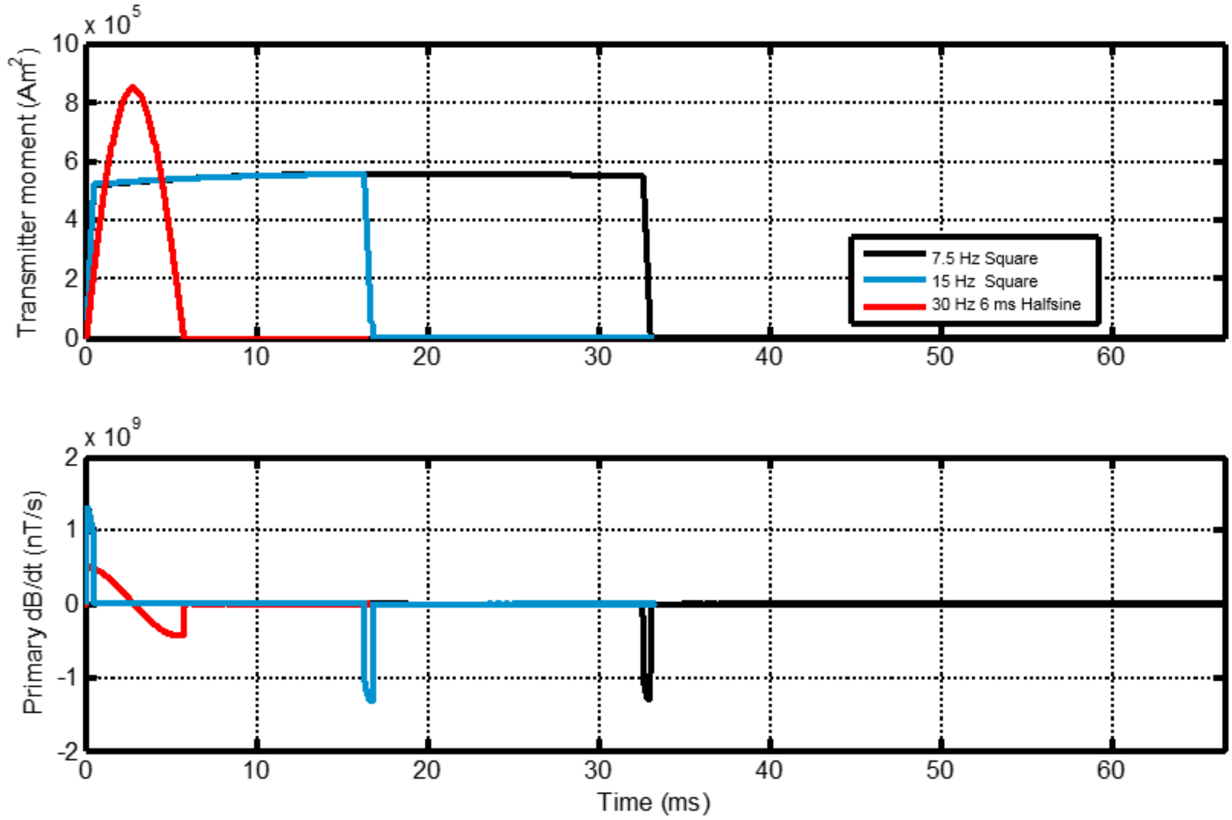

Figure 2. Waveforms used in the test block.

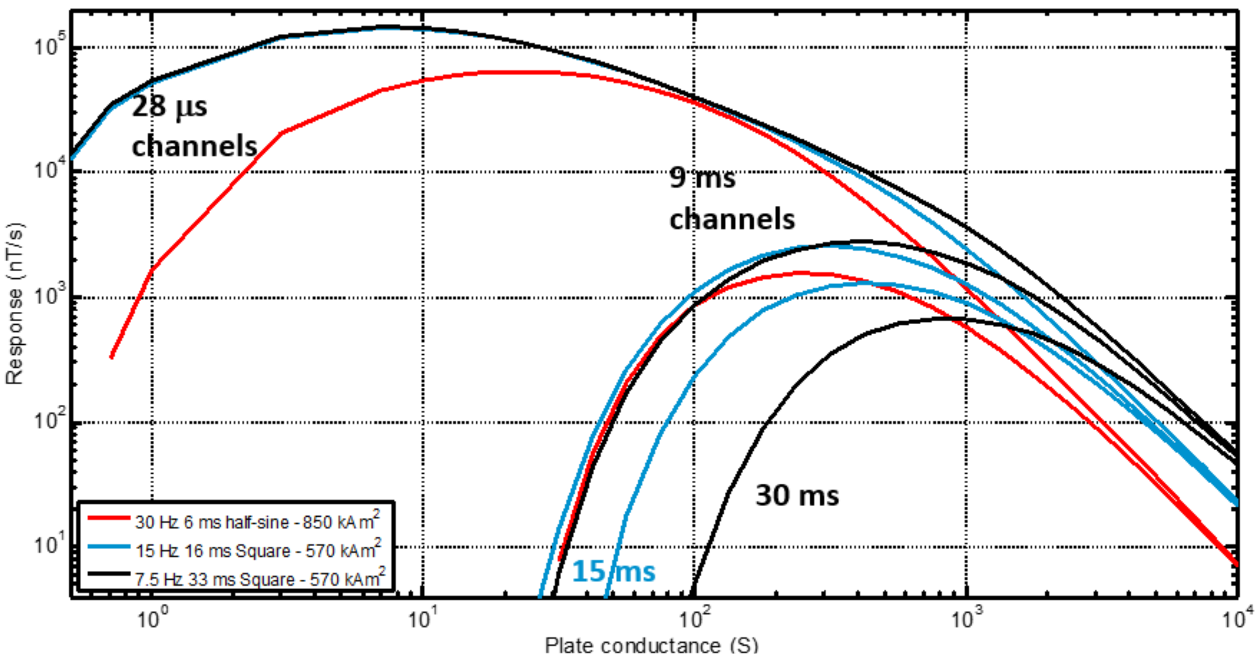

Figure 3. Thin plate nomogram for the waveforms shown in Figure 2. The channel time (after the end of the pulse) is indicated. The 15 Hz and 7.5 Hz waveforms have a longer off-time and their last channel has been plotted as well.

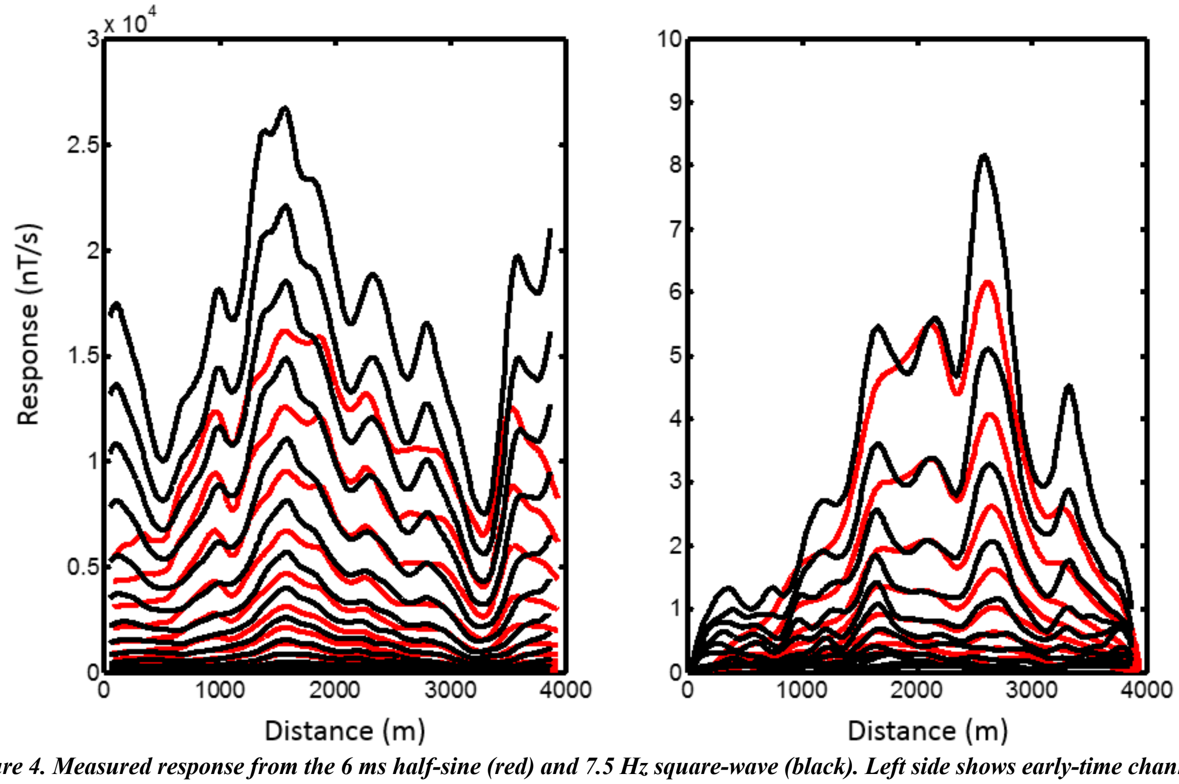

Figure 4. Measured response from the 6 ms half-sine (red) and 7.5 Hz square-wave (black). Left side shows early-time channels. Right side image shows late-time channels (from 3 ms after the end of the pulse).

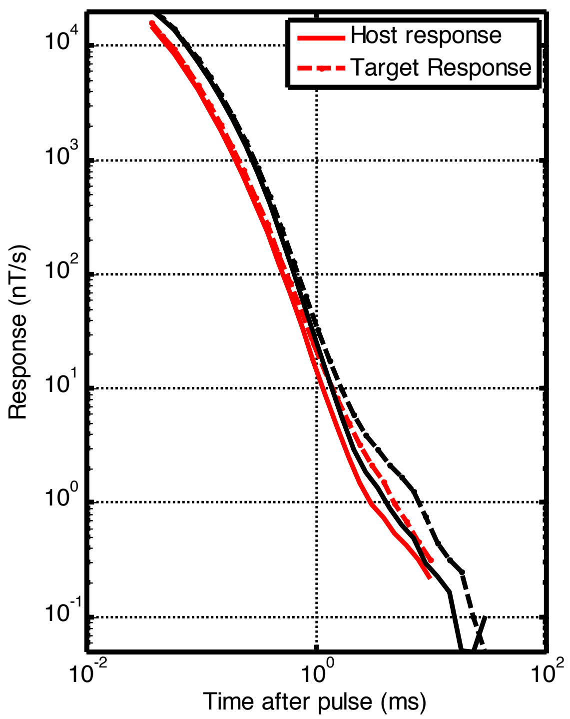

Figure 5. Measured transient decay from the 6 ms half-sine waveform (red) and 7.5 Hz 33.3 ms square waveform (black) above the 300 S target (dashed lines) at position 1,700 m in Figure 4 and the background response (solid lines) at position 1,400 m.