P065
Improving Signal-to-Noise Ratio Using Pseudo Random Binary Sequences in Multi Transient Electromagnetic (MTEM) Data

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SUMMARY

We present multi-transient electro-magnetic (MTEM) data using a step-function and a pseudo-random binary sequence (PRBS) as the source time function. We may recover the earth impulse response from either data set and integrate the result to obtain the corresponding step response. Results show that the PRBS waveform recovers the same result as the step in current but in a much shorter time.
Introduction

We present multi-transient electro-magnetic (MTEM) data using a step-function and a pseudo-random binary sequence (PRBS) as the source time function. We may recover the earth impulse response from either data set and integrate the result to obtain the corresponding step response. The MTEM setup is shown in Figure 1. The layout is similar to 2-D seismic reflection.

![Figure 1 A typical MTEM source-receiver configuration, with a current bi-pole source and its two electrodes A and B, and a line of receivers in line with the source, measuring the potential between pairs of receiver electrodes, for instance C and D.](image)

Uncorrelated random additive noise can be reduced by vertical stacking with a reduction in noise of \( \sqrt{n} \) where \( n \) is the number of traces being stacked. The input signal can be increased by increasing the source dipole moment which is the product of the source current \( I \) and the source dipole length \( \Delta x_s \). The received signal can also be increased by increasing the receiver dipole length \( \Delta x_r \). Limits on the size of the source current are imposed by the source equipment and limits on the size of the source and receiver dipoles are imposed by the need for the dipole approximation to be valid, this means that the nearest offset at which data can be recorded is approximately five dipole lengths. In general the source current and source and receiver lengths are as large as possible and cannot practically be increased. As a result the only way to increase the signal to noise ratio of the data is to stack a very large number of traces. The amplitude of the EM signal falls off rapidly with offset and so targets at depth or in conductive areas become commercially unfeasible due to the amount of time needed to collect data of good quality at each source location.

Another way to increase the signal-to-noise ratio is to input a long coded sequence as the source waveform instead of a single step function. PRBS data contain signal plus noise; the signal is correlated with the PRBS sequence, the noise is not. For a PRBS, the signal-to-random noise ratio increases as the square-root of the length of the sequence and requires much less total recording time to achieve a given signal-to-random noise ratio than simply stacking repeated measurements.

PRBSs

A pseudo-random binary sequence (also known as a pseudo noise (PN) sequence) consists of a deterministic sequence of pulses which will repeat itself after its period. A PRBS is defined by two parameters, known as the clock frequency \( f_c \) and the sequence order \( n \). The sequence will repeat after \( 2^n-1 \) clock pulses. Like truly random noise the amplitude spectrum of a PRBS is flat. Figure 2 shows a PRBS and its amplitude spectrum. Note the PRBS switches from +1 to -1 because it is desirable to maintain constant power and it is possible to reverse the polarity in a very short space of time.
A PRBS also has the property that its autocorrelation function is an impulse of amplitude $2^n-1$ at zero lag and -1 everywhere else. Processing PRBS data therefore allows the impulse response of the earth to be recovered.

PRBS waveforms have previously been used as a source waveform for EM surveying. The first application was by Quincy (1974) using a loop-loop system; later Duncan et al. (1980) used a PRBS waveform with a grounded dipole source; Helwig (1999) then compared a step input with a PRBS input for LOTEM field data, showing the clear gains in signal-to-noise ratio that can be achieved. More recently Hornbostel (2005) used two classes of coded waveforms in order to try and detect signals that were 2-5 orders of magnitude below the ambient noise level in electro-seismic exploration.

**PRBS Processing**

Processing of PRBS data conventionally uses correlation techniques to recover the earth impulse response. That is, the recorded data are cross-correlated with the input PRBS sweep to recover the earth impulse response. This is the approach used in the previous studies discussed above. Because the field data are the result of the convolution of the PRBS signal with the earth impulse response the earth impulse response can also be recovered by deconvolution instead of cross-correlation. Figure 3 illustrates the idea.

In practice, of course, the load on the source varies with the resistance of the earth and the impedance of the circuit and the actual current may not be the same as the PRBS driving function. In the MTEM method the actual current input to the ground is measured.
Field data examples
A field test using a PRBS source waveform of length $2^{12} - 1 = 4095$ was made and the processed results compared with results obtained at exactly the same location using a step input in current. The measured source current waveform and the received signal for a step input and a PRBS input are shown in Figures 4 and 5 respectively.

Figure 6 (left) shows the earth impulse response recovered for 3 three different lengths of listening time. Figure 6 (right) shows the recovered step response for a step input in current, after deconvolution for the source current measurement, and the step responses obtained by integrating the impulse responses shown in Figure 6 (left). It can be seen that there is an extremely good match between the result obtained for a step input and that obtained using the PRBS waveform which indicates that the deconvolution approach applies equally to step response and PRBS data.

Figure 4: Left: A source current measurement for a step input. Right: A step response recorded at a receiver some distance from the source.

Figure 5: Left: A source current measurement for a PRBS input. Right: The response at a receiver some distance from the source.

Figure 6: Right: The deconvolved step response for a step input (green) and the result of deconvolution for a PRBS input to recover the impulse response followed by integration to obtain the step response for three different listening times at the same location.
Figure 7 shows the signal-to-noise improvement that can be obtained when using a PRBS. Figure 7 (left) shows the recovered impulse response for a shot gather where 50 PRBS traces of length 4095 were stacked. Figure 7 (right) shows the impulse response obtained by differentiating the recovered step response where 1550 step responses were stacked.

Figure 7:   Left: A shot gather showing the impulse response recovered by deconvolution from a PRBS waveform. Offset increases from right to left. Right: A shot gather showing the impulse response recovered from a step input after differentiation.

Conclusions
The use of PRBSs in MTEM surveying allows data with a better signal-to-noise ratio to be obtained in a shorter time. Deconvolving the recorded data for the input PRBS sequence rather than cross correlating has been shown to work.

References

