

# Significantly increasing TEM survey performance by modifying frequency content of transmitter waveforms

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## ABSTRACT

TEM surveys typically operate with a simple transmitter waveform, such as a 50% duty cycle alternating square wave. The frequency of transmission and the duration of measurement is decided before the survey or, frequently in the case of ground TEM surveys, adapted during the survey by the operator to suit the conditions.

With some sensor types in particular, achieving good quality data throughout all parts of the decay is difficult. Additionally, all surveys can be complicated by the presence of external sources of interference such as power transmission lines. We argue that significant improvements can be made by optimising the frequency content of the transmitter waveform. Additionally, in the case of ground surveys, the duration of an individual reading can be controlled in order to achieve rapid production and desired data quality. Variables are the EM noise spectrum (a function of the sensor and environment) and the conductivity of terrain. These change along the TEM profile and best results are obtained by regular re-evaluation in light of the target sought.

There are several options available to modify the effective frequency content of a TEM transmitter waveform. For a conventional square wave transmitter, an irregular pattern of polarity reversals can be transmitted. Another method is to use two or more base frequencies sequentially. The survey can be automated and data can be combined automatically into a single decay with optimal signal-to-noise ratio over the entire decay.

Examples will be presented to illustrate improvements in performance.

**Key words:** TEM, noise, transmitter, signal processing

## INTRODUCTION

Transient electromagnetic (TEM) surveys effectively measure electromagnetic (EM) response over a wide range of frequencies. However, for many scenarios, TEM systems can not deliver good quality data over all frequencies required by the interpreter.

TEM transmitters are typically operated at a single repetition rate (base frequency) in a given survey. This choice can have a significant impact on the ability of the TEM system to detect, discriminate and map targets – especially if a range of geological features are present with a range of electrical conductivities.

Some TEM sensors perform well in some parts of the EM spectrum and comparatively poorly in others. It is not always possible to perfectly match the sensor available to the survey that it must perform.

Due to the broadband nature of TEM surveys, they are often further complicated by the presence of interference from external sources such as power

transmission lines, atmospheric discharges and the effects of wind or vibration on sensors.

We have no control over many of the issues affecting the quality of TEM data resulting from a survey however it is useful to consider optimising the transmitter base frequency or changing the type of waveform transmitted in order to increase data quality. There are a number of precedents for this, including seismic systems, radar systems and the UTEM system (West et al, 1984).

## SIGNAL / NOISE ISSUES WITH TEM SURVEYS

Signal-to-noise (S/N) ratios for TEM data can be considered as a function of frequency or delay time. They depend on a number of factors. The *signal* in a given survey is a function of the transmitter waveform and *noise* is a function of the receiver sensor, other elements of the receiver and the environment. Once the sensor, data acquisition system and survey layout have been optimised one of the only useful options remaining

in the quest for better S/N is to optimise the transmitter waveform. This is not a new idea in geophysics but it is worthy of further discussion in the light of typical transmitters used in TEM surveys.

Most TEM systems employ transmitters that transmit a simple bipolar square waveform for which the base frequency can be controlled. Changing the transmitter base frequency and/or modifying the waveform affect the spectrum of the signal received. In parts of the EM spectrum where S/N is poor it can be useful to increase signal by increasing transmitter current at these frequencies.

Options for non-standard (but possible) waveforms are: (1) a combination of high and low frequencies combined in a single transmission (“multi-frequency”), (2) two or more frequencies transmitted, one after the other, producing multiple readings at a single site or (3) a “chirp” waveform in which frequency varies continually within the transmission. We will be comparing the results of non-standard waveforms with a standard 50% duty cycle reading. We will consider only non-standard waveforms in which off-time measurements can be made.

Figure 1 shows a comparison of relative transmitter current spectra for a number of waveforms at base frequency of 0.125 Hz. Amplitude of current falls off approximately as 1/frequency for standard waveforms at 50% or 100% duty cycles. The spectrum of a waveform with base frequency 11 times higher (1.375 Hz) is also shown here to indicate the change caused by introducing higher frequencies

## **IMPROVING PERFORMANCE OF SOME SENSORS**

As an example, consider the case of a TEM survey with a fluxgate magnetometer sensor. Fluxgates have become popular sensors for B-field TEM surveys, especially in more conductive terrain or in the exploration for very good conductors. Compared with a conventional coil sensor, fluxgate magnetometers have lower noise levels at low frequencies (in the vicinity of 1 Hz, say) and higher noise level at higher frequencies (in the vicinity of 100 Hz and above, say). If signal levels are low as a result of terrain that is not particularly conductive then, in the case of the fluxgate sensor, it is the higher frequencies where S/N is likely to be unacceptable. Another example of a sensor that has very good performance at low frequency and relatively higher noise at high frequency is the caesium vapour scalar magnetometer. The low frequency performance of this sensor has been exploited recently for surveys in which the target is extremely conductive.

To illustrate the effects of modifying the signal spectrum we add realistic noise to a synthetic decay.

Synthetic decays were calculated for a half-period of 50% duty cycle and a chirp waveform at a base frequency of 0.125 Hz (see Figures 2 and 3). The time scale for Figure 3 is logarithmic to illustrate nature of the chirp waveform used.

Noise measured on a real caesium vapour magnetometer sensor (Figure 4) is added to these signals and they are then processed. Windowed signals are calculated for the off-times of both waveforms (Figure 5). The windows from the chirp waveform are processed in an algorithm that fits exponentials to it and deconvolves to a step response. Figure 5 shows the processed 50% duty cycle data and the processed chirp waveform data on a logarithmic plot for comparison. Figure 5 also shows the noise-free 50% duty cycle waveform and the noise-free step response. The difference between the desired (noise-free) and resulting responses for 50% duty cycle and deconvolved chirp are shown on a linear vertical scale in Figure 6.

The result of the chirp waveform processing shows an improvement in quality at early delay times compared to the conventional 50% duty cycle data. This follows from the enhanced signal at higher frequencies in the chirp waveform relative to the conventional 50% duty cycle measurement.

## **IMPROVING PERFORMANCE IN NOISY ENVIRONMENTS**

If external noise is compromising S/N then we may counter the effects of the noise somewhat by increasing signal at the frequencies affected.

To simulate a power transmission line interference problem we add a significant quantity of harmonic noise to our waveforms, at 50 Hz and harmonics thereof.

As per the previous example, the noise is added to the synthetic waveforms and the waveforms are windowed. The resulting windows from the chirp example are deconvolved and a comparison of results is displayed in Figure 7.

Figure 7 shows the improvement resulting from transmitting the chirp waveform. The improvement in data quality is significant across most of the decay. The results from processing the 50% duty cycle data are now considerably degraded in quality.

In modern TEM receivers most of the attenuation applied to power line transmission interference occurs at the stacking stage of the signal processing. However, in some cases the base frequency of the transmitter and the sheer amplitude of the interference conspire to result in some of the interference leaking through to the final processed data. The modified transmitter waveforms proposed here (such as the chirp waveform) have the

potential to improve the quality of data where this is a problem. The chirp waveform has higher signal at high frequency in general, not just at the affected noisy frequencies. A more targeted transmitter waveform would produce even better results.

### CONCLUSIONS

We have shown that TEM surveys using standard equipment can benefit from transmitting a non-standard waveform resulting in superior S/N over the frequency range of interest. The result will be enhanced interpretability and more rapid data acquisition.

We believe that TEM systems will eventually automate the process of transmitter control so that data of optimal quality will be collected efficiently.

### REFERENCES

West, G.F., Macnae, J.C. and Lamontagne, Y. (1984), "A time-domain EM system measuring the step response of the ground", *Geophysics* 49, 1010-1026.

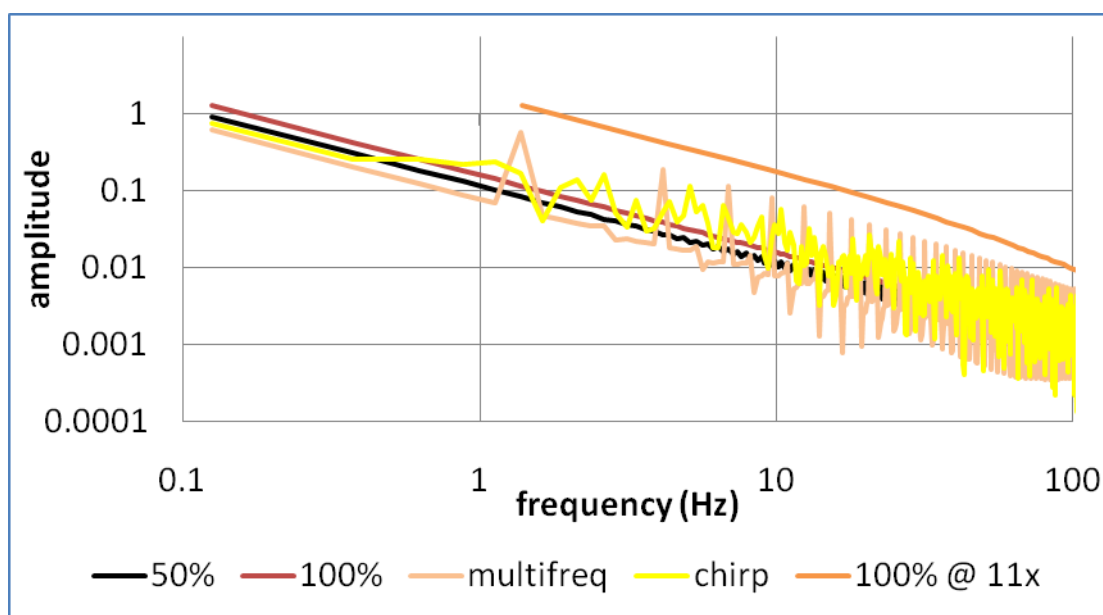


Figure 1 Relative Transmitter Amplitude Spectra for a Range of Transmitter Waveforms with Base Frequencies 0.125 Hz and 1.375 (11 x 0.125) Hz

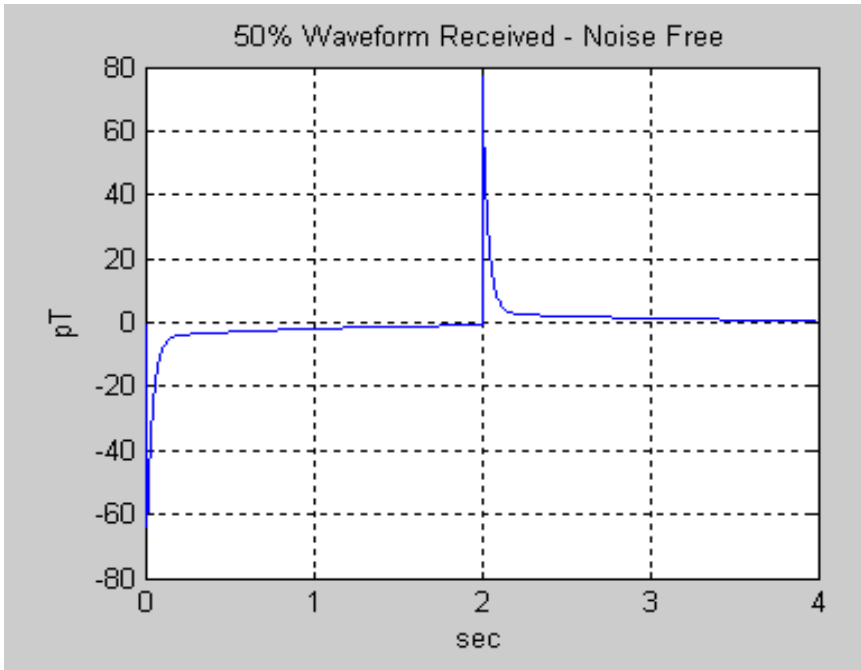


Figure 2 Half-Period of Calculated 50% Duty Cycle Response

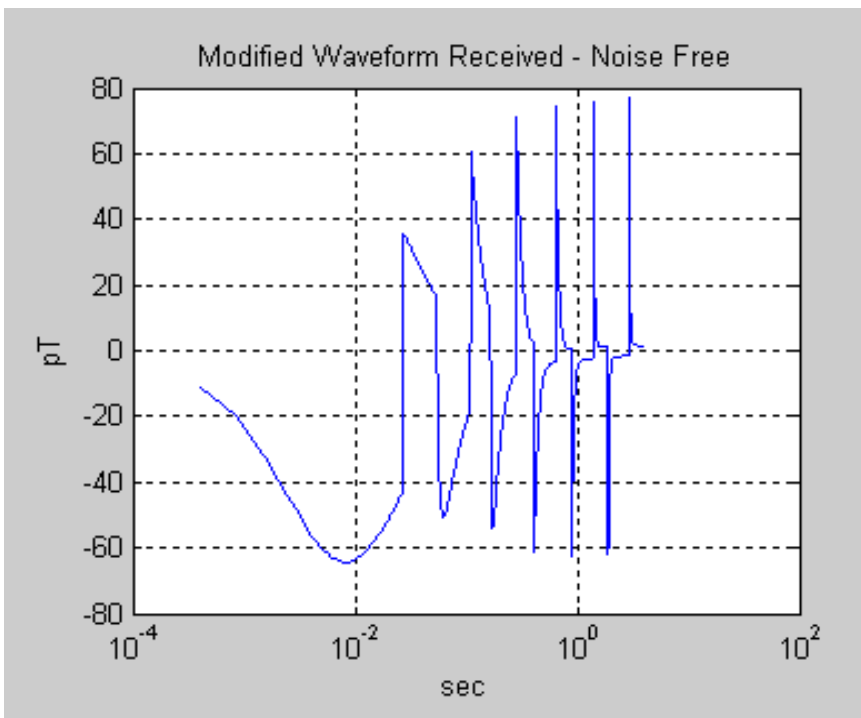
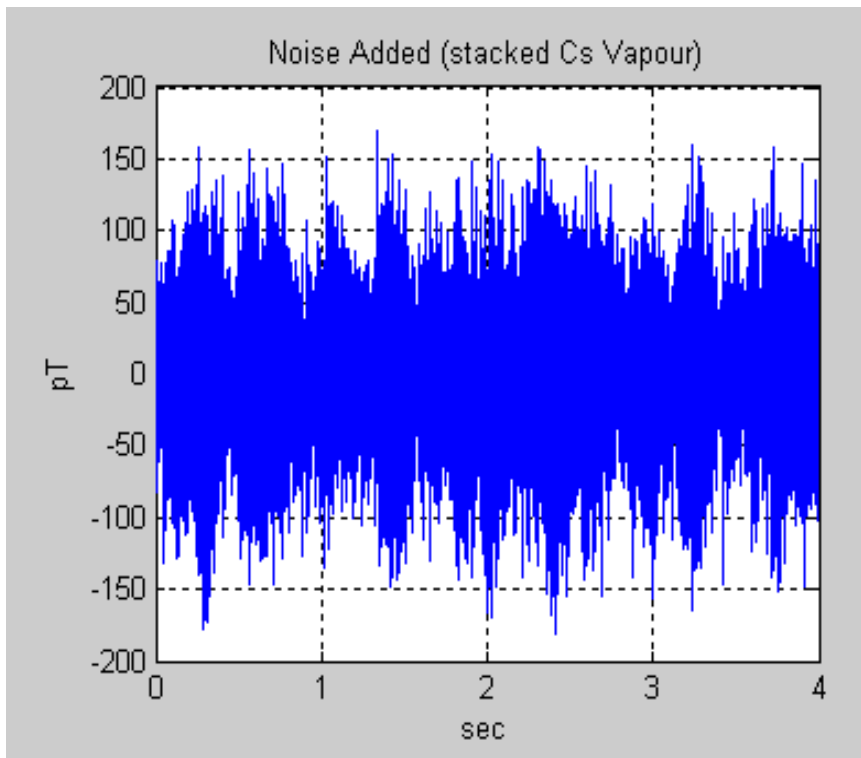
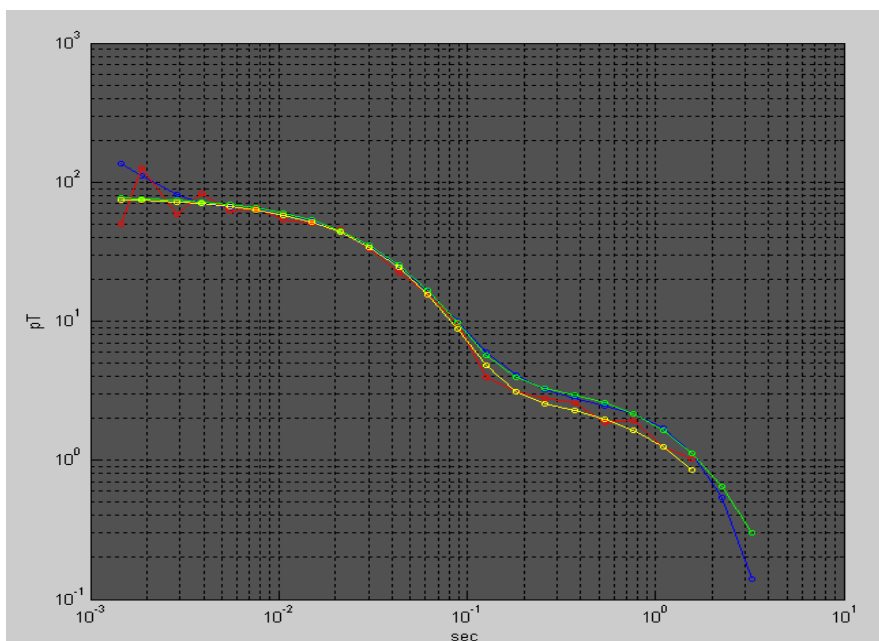


Figure 3 Half-Period of Calculated Chirp Response



**Figure 4** Noise Added to Synthetic Signals – Stacked 0.125 Hz Waveform from a Caesium Vapour Magnetometer



**Figure 5** Windowed Decays: Blue = Step Response Calculated from Chirp, Green = Noise-Free Step Response, Red = 50% Duty Cycle Response, Yellow = Noise-Free 50% Duty Cycle Response

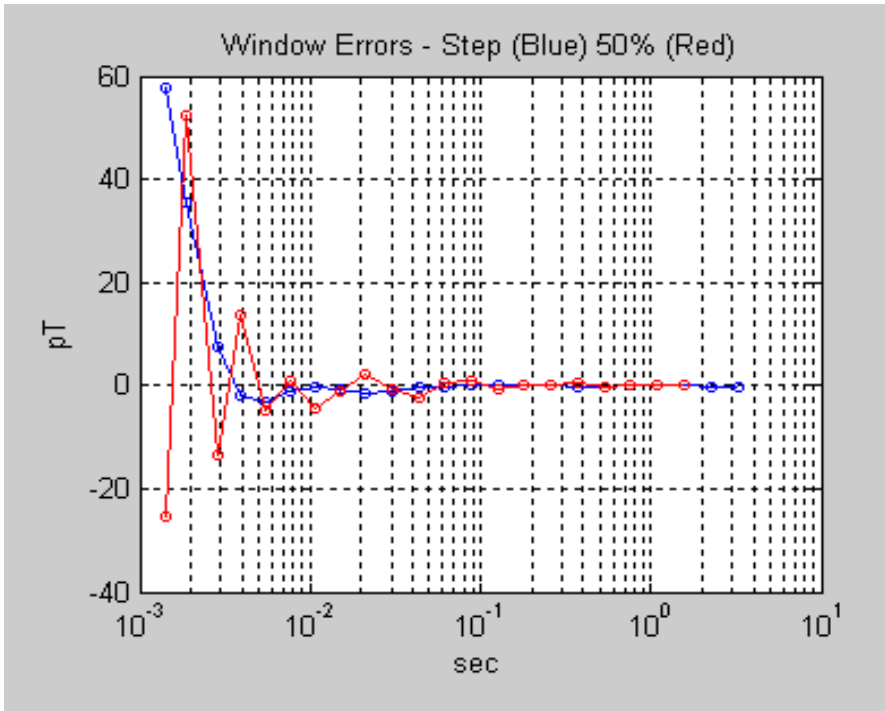


Figure 6 Difference Between Noise-Free Step Response and Step Response Derived from Chirp (Blue), Difference Between Noise-Free and Processed 50% Duty Cycle (Red)

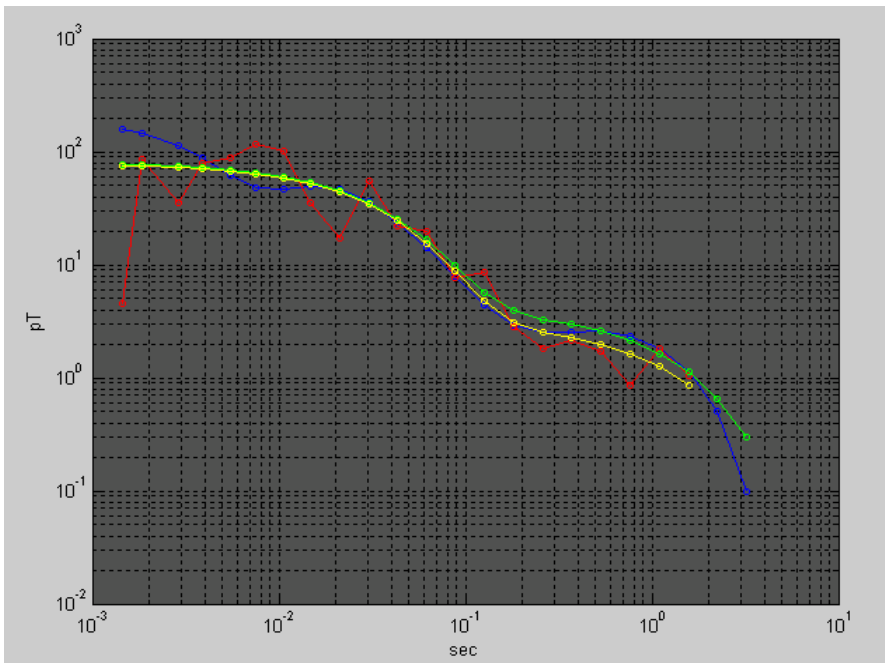


Figure 7 Windowed Decays From Experiment with Power Line Interference Added: Blue = Step Response Calculated from Chirp, Green = Noise-Free Step Response, Red = 50% Duty Cycle Response, Yellow = Noise-Free 50% Duty Cycle Response