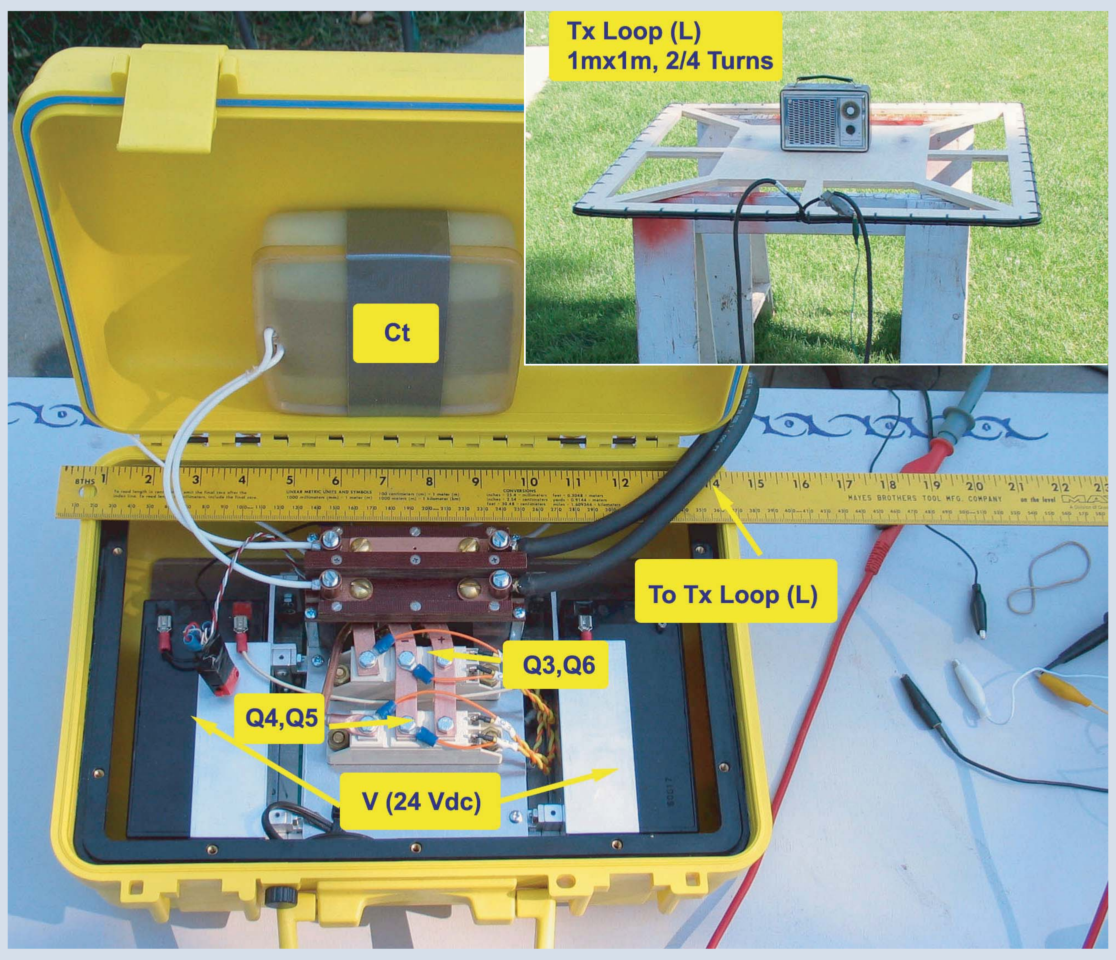
Improved Methods for Detection and Classification of UXO Using Broadband Transient Electromagnetic Techniques

Donald D. Snyder III, Snyder Geoscience, Inc.
Scott C. MacInnes, Kenneth L. Zonge, Jennifer L. Hare, Zonge Engineering & Research Organization, Inc.
Mary M. Poulton, Department of Mining and Geological Engineering, University of Arizona

Objectives

Precision broadband electromagnetic induction (EMI) measurements can provide useful information for classifying buried metal objects such as UXO. But classification using EMI measurements is dependent on the precision of the position and orientation (i.e. heading, pitch, roll angles) of the antenna array and on the signal-to-noise (SNR) level of the observed data. These data attributes are degraded in dynamically acquired data. In this paper, we report on two projects funded by SERDP that investigate methods for improving classification and detection using the TEM method. The approaches under investigation are:

- Increasing SNR with a High Powered TEM Transmitter
- Rapid Static Mode Data Acquisition for Queued Target Identification



Project Status

Zonge Engineering has assembled a high-power TEM transmitter based on resonance techniques. The transmitter emits a short high amplitude pulse of current with the shape of a half-sine wave. Preliminary experiments show that transmitter moments between 1000-1500 A-m^2 can be achieved with current pulse-widths as short as 30-60 ms, an increase in the transmitter moment by a factor of approximately four- to six-times the reported transmitter moment of an EM-61 (~200 A-m^2) and by a factor of 60 in the moment of the Zonge Dynamic NanoTEM (DNT) system (~25 A-m^2). We have completed the construction of the transmitter, and we are beginning to test its performance relative to conventional TEM systems.

High Power TEM Transmitter

Background

Since the late 1950's, airborne TEM systems have been highly successful in finding mineral deposits and in mapping geology. These transmitters drive the transmitter loop with bipolar current pulses with a half sine wave shape. Conventional TEM systems transmit a series of long bipolar current pulses. The abrupt termination of the current pulse (time rate-of-change of current) generates the EM induction.

Two current waveforms are illustrated below in Figure 1 (left panel). Most ground-based TEM systems use a transmitter waveform such as that shown in red; airborne TEM systems typically use a half-sine pulse waveform in order to generate the higher moments necessary for airborne operations (blue curve). These two current waveforms produce secondary transients with different characteristics. The time derivative of the current shown in the right panel of Figure 1, for example, drives induction EM. Equally important, however, is the fact that the peak transmitter moment (i.e., turns x Area x Current) for the half-sine waveform is usually much higher than the moments generated with conventional transmitter waveforms.

Can a TEM system driven by a half-sine pulse type transmitter improve UXO detection? With SERDP funding, Zonge Engineering is conducting research to determine the answer.

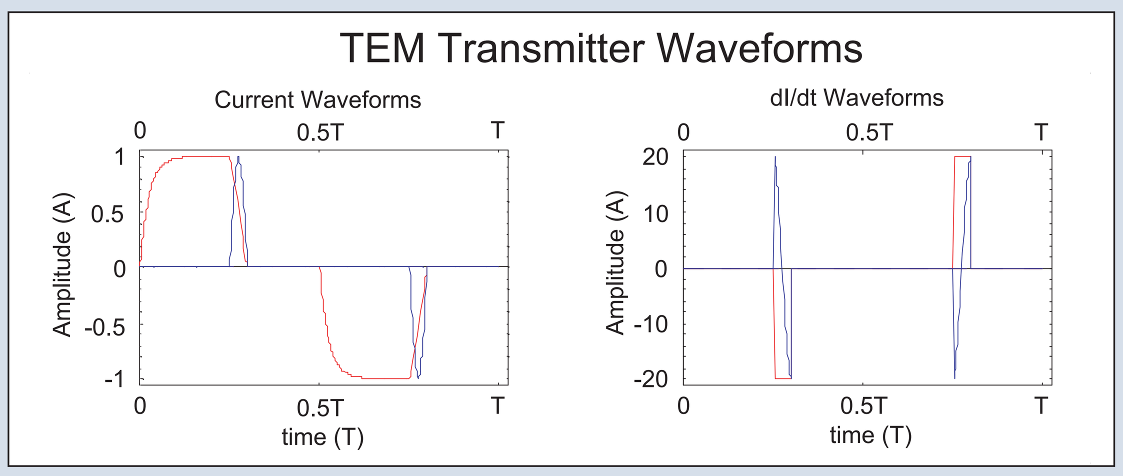


Figure 1. Comparison of conventional (red) and half-sine pulse type (blue) TEM transmitter waveforms.

Motorized Gantry System for Dynamic-mode Testing

The prototype ZRT-500 transmitter is pictured above mounted to a motor-driven gantry system. The motorized gantry was built by Zonge Engineering in order to test the prototype transmitter "head-to-head" with the Zonge NanoTEM system which operates with a fast conventional TEM waveform. Test targets can be mounted at various heights below the antenna and dynamic surveys are simulated at variable controlled speeds. Both the gantry system and the ZRT-500 prototype have been completed as of November, 2003, and plans are underway to conduct dynamic tests over target items in the upcoming fiscal year

Prototype Transmitter Testing

At upper left is a photograph of the prototype resonance transmitter ZRT-500. We have tested it into 1-, 2-, and 4-turn loops of heavy gage wire. Within the design specifications of the hardware (principally the SCR switches and the tuning capacitor), the transmitter performs best into a 2-turn loop. With a 2-turn 1m x 1m transmitter loop, the user can select either a 30us pulse width or a 60us pulse width. Figure 2 (below left) shows the current waveforms for the pulse widths while being driven with a 24Vdc supply.

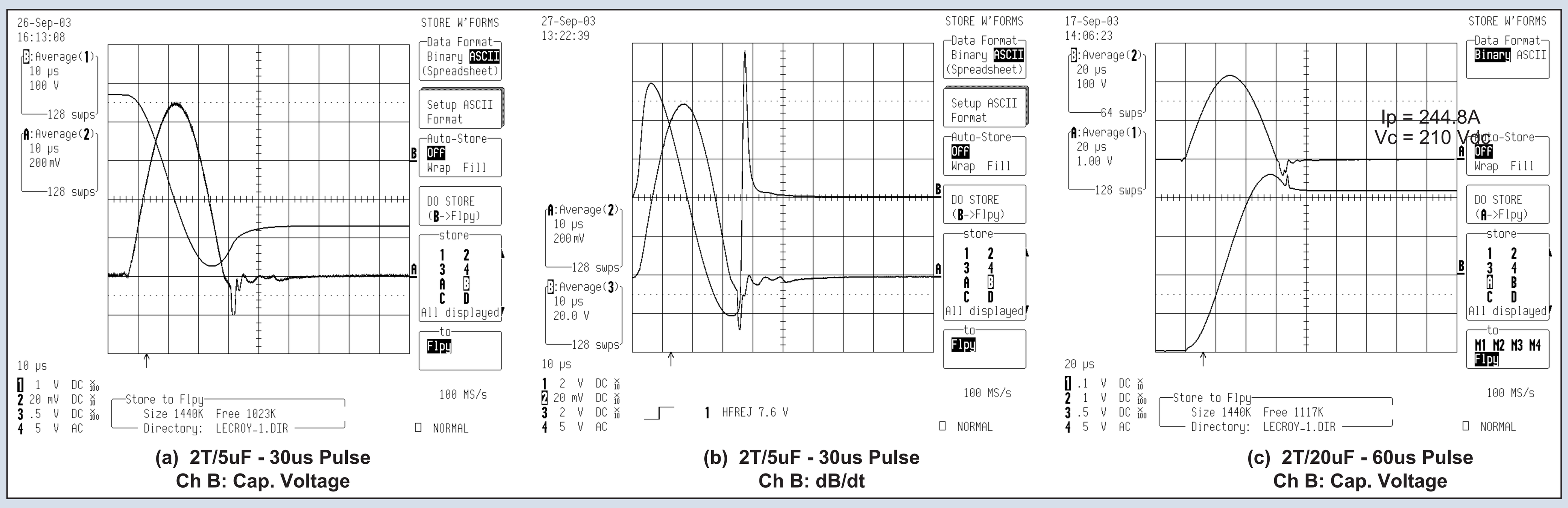
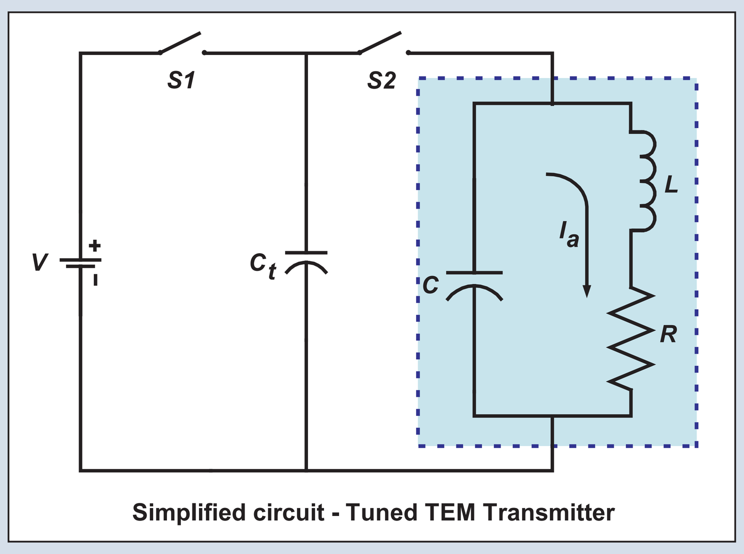


Figure 2. Oscillographs of measured current and voltage waveforms output from the prototype ZRT-500.

ZRT-500 Features

- Half-Sine Pulse Current Waveform
- Battery-Power
- Selectable Pulse Width
- Suitable for man-portable, towed vehicle, or low-level airborne applications



Simplified circuit - Tuned TEM Transmitter

Resonance Principles

Half-sine TEM transmitters are based on resonance principles of LRC circuits. The shaded portion in the circuit diagram (above right) includes the elements of a tuned transmitter loop. A "tuning" capacitor (Ct) has been added to the circuit to set its resonance frequency (f0) at a desired value. There are four switches (Q3/Q4, and Q5/Q6) forming an H-bridge, and a voltage source (V). This circuit generates a bipolar current waveform similar to that shown in Figure 1 (right side, blue curve). The resonance frequency of the circuit is determined by the value of the tuning capacitor according to the relation:

$$f_0 = \frac{1}{2\pi\sqrt{LC_t}} \qquad (1)$$

The transmitter pulse width is: $w = 1/(2f_0)$

Waveform Bandwidth

The resonance transmitter can generate significantly higher moments (Current x Area x Turns) than existing conventional transmitters. Figure 3 (right) compares the transmitter moment and moment-bandwidth product for the resonance transmitter and antenna configurations evaluated in our research against both the Zonge NanoTEM® and the Geonics EM61 systems, conventional TEM systems currently used for UXO detection and classification. The resonance transmitter offers significant improvement in both momentand moment-bandwidth product over conventional systems.

Figure 1 (above) shows the derivative of the transmitter current for the two types of transmitter waveforms. These waveforms are indicative of the time rate of change of the magnetic induction field (dB/dt) that drives EM induction. It is useful, therefore, to compare the Fourier spectra for these waveforms because they suggest that SNR advantages accrue to the resonance transmitters at higher frequencies.

Figure 4 (below right) compares dM/dt spectra for a 60us half-sine current pulse (Ip = 217A), the Zonge NanoTEM system, and the EM-61. The Figure shows that the half-sine pulse has a significantly higher amplitude spectrum than common conventional transmitters at frequencies above approximately 5KHz suggesting that, at early delay times (e.g., t < 200 μs), we can expect substantially higher signal-to-noise (SNR) and hence a more sensitive system for target detection.

Figure 5 (left) shows the expected response for a 4-in sphere for both the conventional waveform with 10 μs and 100 μs ramp times and for half-sine wave Tx waveforms with various pulse widths. The figure confirms the conclusions we made from Figure 4, namely that the advantage of the half-sine pulse waveform is confined to early time.

The moments indicated in Figure 5 are consistent with those that we obtained using the prototype ZRT-500 powered by a 24Vdc primary power supply. These moments can be easily doubled using a 48Vdc primary power supply.

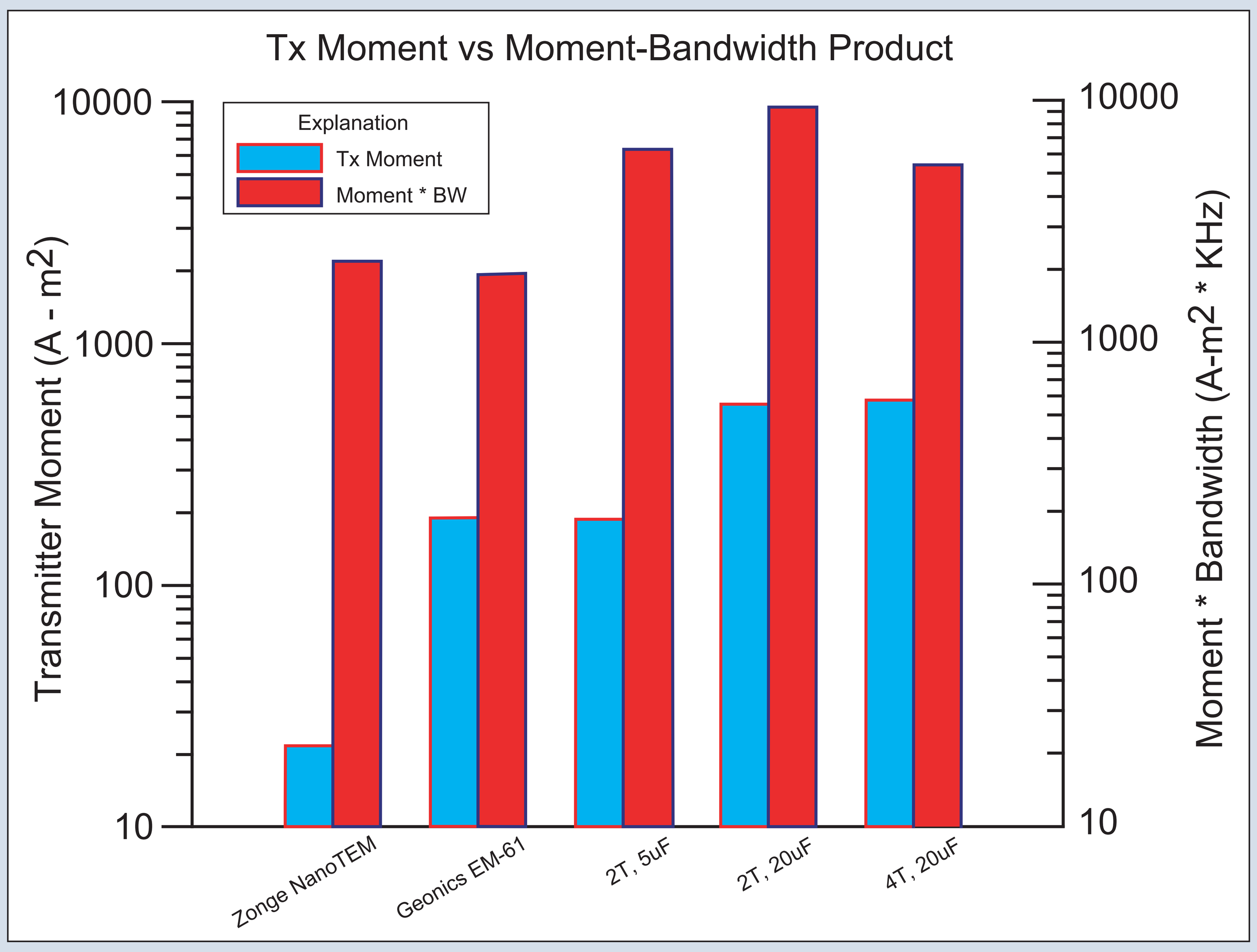


Figure 3. Transmitter moment and moment-bandwidth for two conventional TEM systems and three resonance antenna configurations

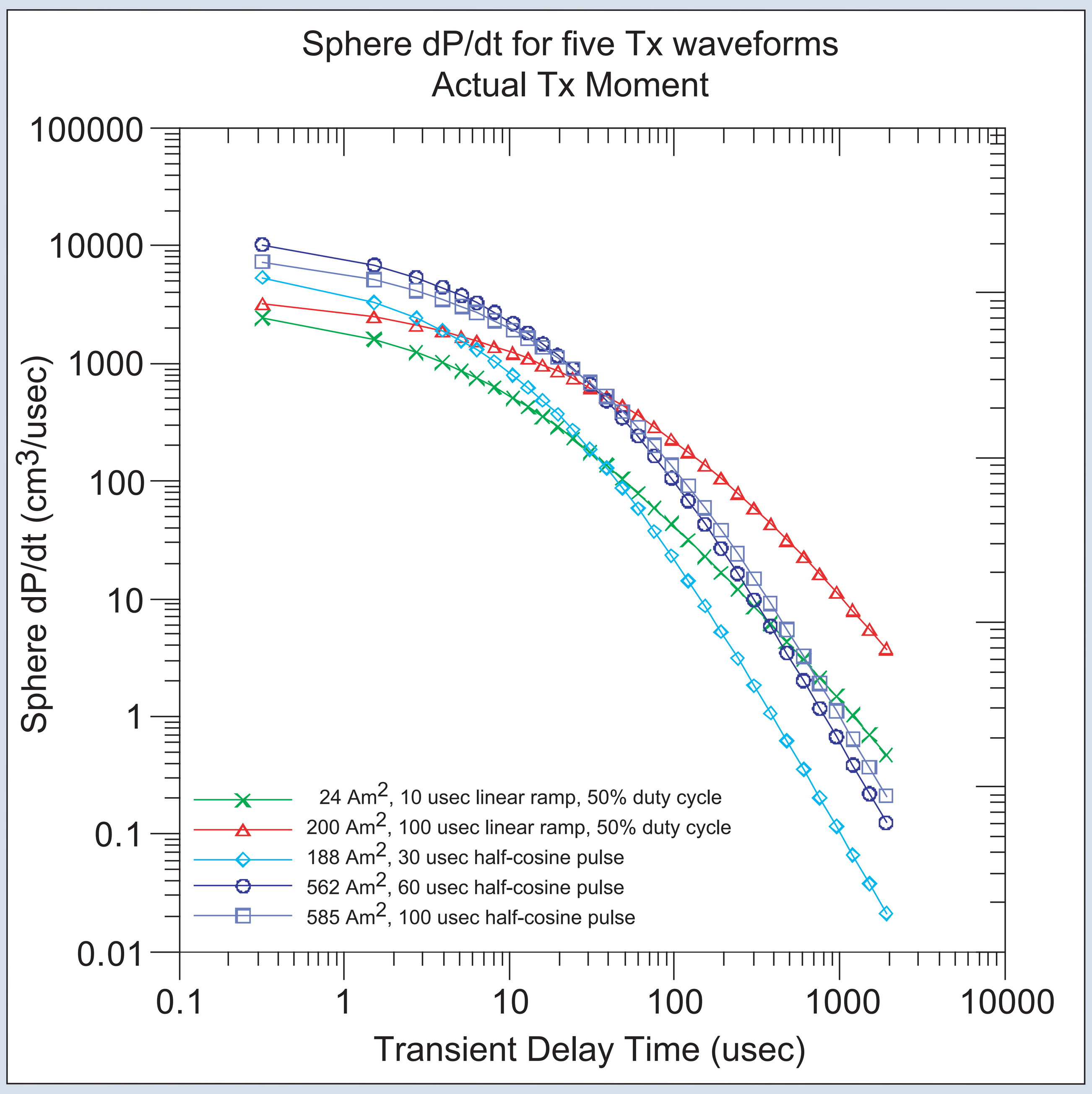


Figure 5. Computed transient response for a conductive permeable sphere for conventional and half-sine TEM current waveforms.

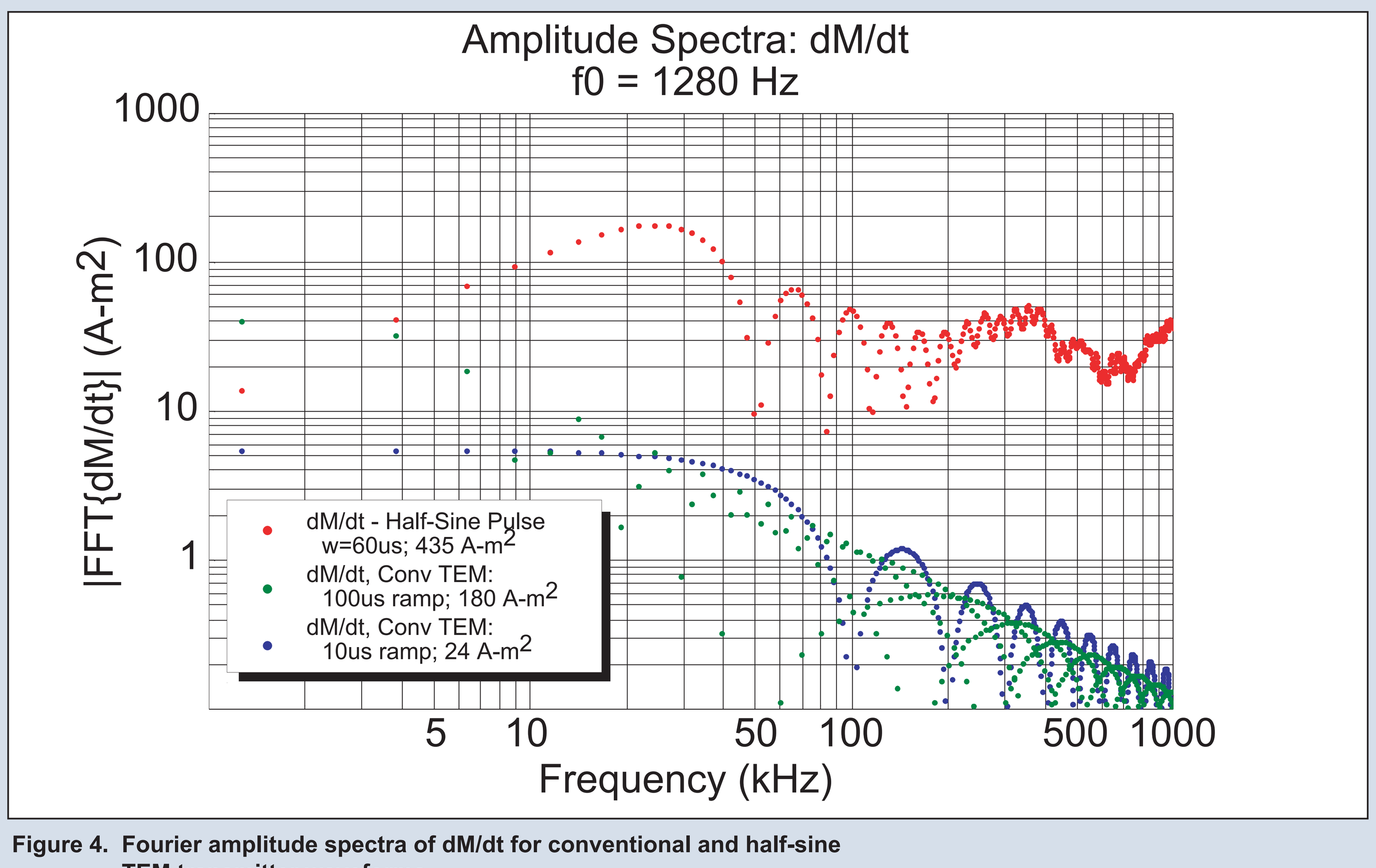


Figure 4. Fourier amplitude spectra of dM/dt for conventional and half-sine TEM transmitter waveforms