Inset: The UTEM receiver in action on a winter survey in Scandinavia.

Are all TEM systems the same?

There has for many years been a heated debate as to which is the best type of waveform to transmit in a transient electromagnetic (TEM) system. With the current resurgence in base metal exploration and the need to explore at greater depths, this argument becomes more relevant than ever. The aim of this note is to try to show which of the two presently operating system types is the most desirable as applied to the search for deep, massive sulphide bodies. These two system types are known as step response and (im)pulse response systems. Essentially this report is a comparison of the UTEM system and other TEM systems. The formula for comparing relative system response amplitudes for the two system types is derived from basic EM theory so that the comparison may be done quantitatively.

A fair comparison:

The comparison is best based on systems which are identical except for their waveform, that is:

- the same maximum primary magnetic field intensity
- the same survey geometry
- the same coil sensitivity, receiver gain and stacking time
- the same magnetic field noise ('sferic or random transient)
- the same instrumental noise (assumed negligible here)

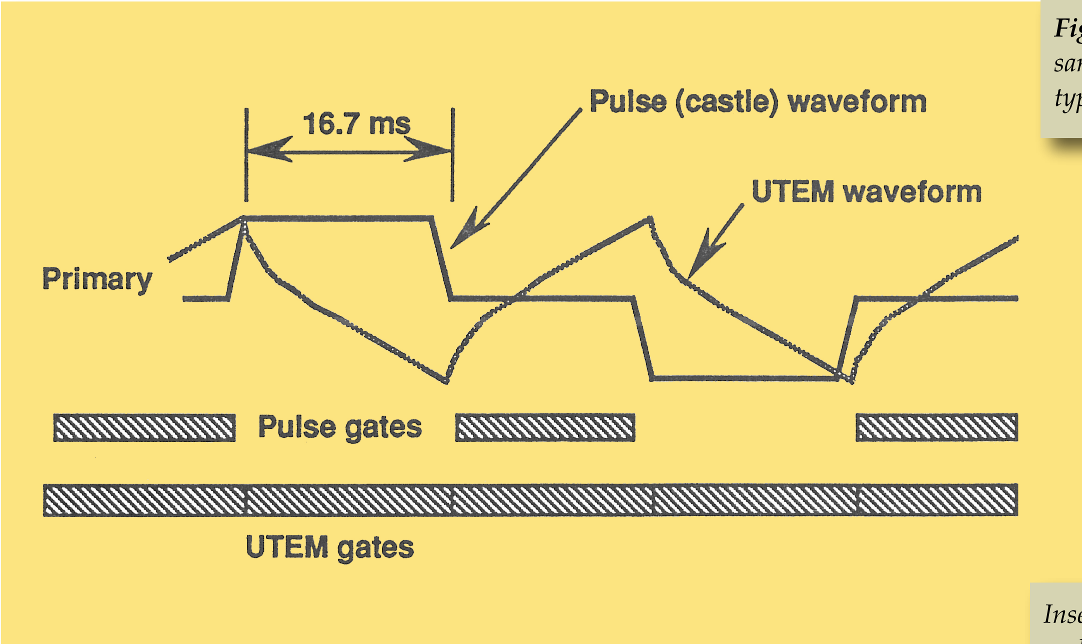


Figure 1: *Current waveforms and sampling gates of the UTEM and typical pulse systems.*

While some differences between real systems exist in detail, such as loop size, transmitter peak current, survey line and loop location, these differences are not profound when the normal field survey operating strategies are compared. For example, many systems operate with small loops and larger currents, others with large loops and smaller currents, however, both have essentially the same magnetic moment.

Comparing "system responses"

The measured response of a TEM system varies depending on the geometry of the target and location with respect to the transmitter and receiver. Generally, however, the response may be represented by a sum of exponential decays. Each decay may be characterized by a time constant T. It is natural then to compare the step and pulse responses of an exponential decay. The final response function, called U(t) for the step response and I(t) for the pulse response, is really comprised of the basic, theoretical response of one transition of the waveform, a single step S(t) or a single pulse P(t), multiplied by various factors, which we might term *system factors*. These factors take into consideration things such as effects caused by the periodic nature of all TEM waveforms, waveform shapes, such as finite pulse width, special signal enhancement techniques involving a transmitter waveform modification, and duty cycle.

Inset: The UTEM borehole probe permits single-pass 3-component measurements.

Inset: UTEM systems have been deployed around the world.

Inset: The UTEM transmitter is easily deployed to remote locations.

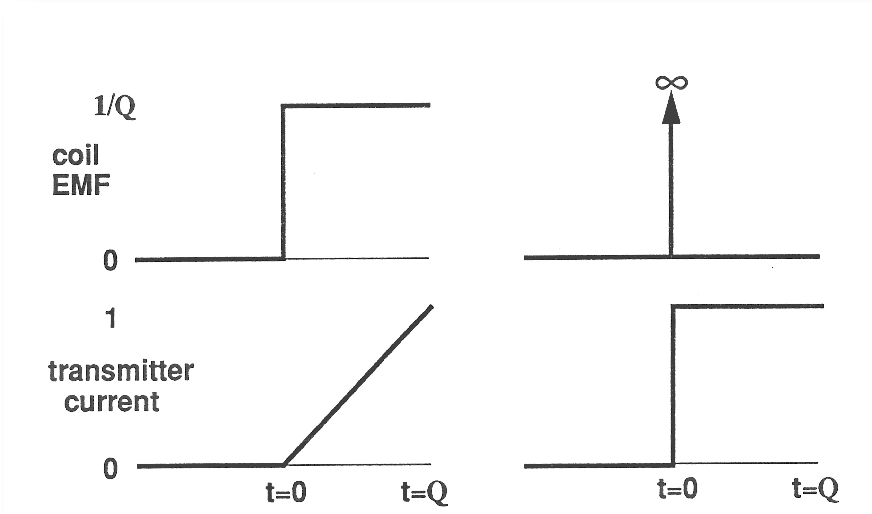


***Figure 2:** The current waveforms and measured signal for a single event for UTEM (left) and pulse systems (right).*

The current waveforms and sampling intervals (gates) are shown for both the UTEM and typical pulse systems in Figure 1. The periodic nature of the current waveform as well as the sampling interval scheme does have a bearing on the final sensitivity of each system, but we will start by considering a single transition of the current waveform. For the sake of mathematical simplicity, the coil sensitivity is assumed to be unity and the peak current at the transmitter is also assumed to be unity for both systems (Figure 2). If Q is the time it takes for the step response transmitter to ramp from 0 to 1 amp, this would give a primary emf at the coil sensor of amplitude 1/Q for the step response system and a Dirac delta function (or impulse function) integrating to 1 for the pulse system.

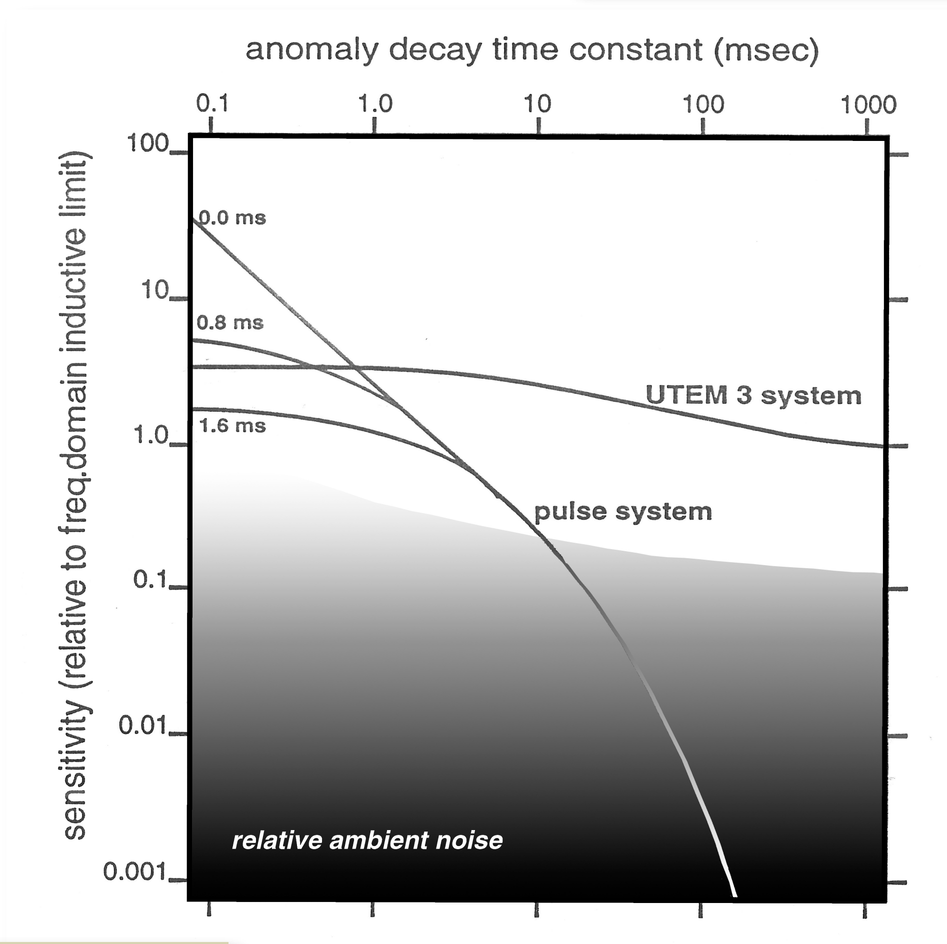


***Figure 3:** A comparison of the UTEM and generic pulse system sensitivity (at 16 ms sampling) normalized to the equivalent frequency-domain inductive limit amplitude over a range of time constants. The approximate typical ambient noise is shown (shaded region).*

The Equation

The system response functions, U(t) and I(t), for an exponential decay may be expressed by the following equations:

U(t) = Wu • Eu • Du • Ru • S(t) and

I(t) = Wi • Ei • Di • Ri • P(t) where

$S(t) = (1/Q)e^{-t/T}$ and

$P(t) = (-1/T)\ e^{-t/T}$

and where

- R is the periodicity factor
- D is the noise window factor
- E is the UTEM noise reduction factor
- W is the pulse ramp width factor

The System Factors

The system factors that comprise the system response factors are as follows:

R : (periodicity factor)

Real step and pulse systems transmit repeating and reversing transitions of the basic step and pulse functions. This fact introduces certain limitations which depend on the width of the half-cycle sampled Q and the time constant of the anomaly T. The function describing this is:

Ru = 4/ (1+g)	(UTEM)
Ri = -(1 - g) / $(1+g^2)$	(impulse)

D : (noise window factor)

The UTEM system samples twice as many transitions in any given time period than do the pulse systems. This results in a net enhancement in S/N of:

Du ~ 2	(UTEM)
Di ~ 1	(impulse)

E : (UTEM noise reduction factor)

The UTEM system employs a transmitter pre-emphasis/receiver de-emphasis filter system which improves S/N in a manner similar to the techniques used in some audio recording/playback equipment. The degree of S/N improvement is a function of the frequency spectrum of the noise being rejected and the time constant of the anomaly T. However, a minimum enhancement may be estimated, so that:

Eu > ~3	(UTEM)
Ei ~ 1	(impulse)

W : (Pulse ramp width factor)

Real pulse systems do not have ramp times that are infinitely short. A waveform with linear primary field ramping over a ramp time w would be:

Wu = 1	(UTEM)
Wi = T(1-h)/w; $h = e^{-w/T}$	(impulse)

Putting it all together

The UTEM and pulse system responses are plotted in Figure 3 as a function of anomaly decay time constant in the range of from 0.1 ms to 100 ms. This covers the approximate range of typical massive sulphide target conductivities. Since all real field measurements are made in the presence of background noise, the typical ambient electromagnetic noise level is also shown. The system responses are normalized so that in the long time constant limit (i.e. very large T) the UTEM response amplitude is the same as the frequency domain inductive limit amplitude for the same simple exponential decay. As a result, the UTEM response has a value of 1 at large T. The sampling interval (Q) is set at about 16 ms, which is the standard used in most reconnaissance surveys in North America and represents a base frequency of 15 Hz for the pulse system and 30 Hz for the UTEM system. The pulse response is plotted for three ramp widths. By definition there is no equivalent ramp width parameter for the UTEM system.

Figure 3 clearly shows that the UTEM system response is more or less flat across the bandwidth of the plot. The only deviation from this is due to the enhancement of the signal in the high frequency range (smaller T values) by the UTEM pre-emphasis/ de-emphasis (E factor) filter system. At all times the UTEM system response is above the background noise. On the other hand, the pulse system response attenuates dramatically for large values of T to the point where the signal level would be lost in the background noise. For an ideal pulse (i.e. a zero ramp width),the pulse system response is larger than that of the UTEM system at values of T less than 1 ms. However, the pulse system high frequency limit is strongly affected by pulse ramp width so that for ramp widths of greater than about 1 ms, the UTEM response is at all times larger than the pulse system response.

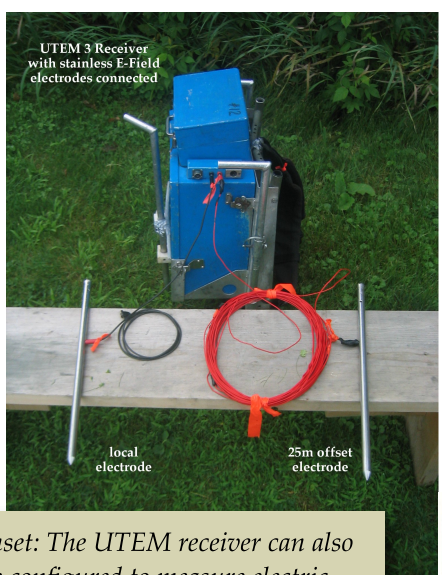
What does this all mean?

All TEM systems are forced to operate in the presence of environmental noise (powerlines, ‘sferics, etc.). Therefore, there is a signal level below which any TEM system is unable to measure a response amplitude reliably. With the UTEM system, the response amplitude is more or less constant regardless of the time constant of the anomaly decay. Therefore, for any given target the UTEM system sensitivity is for the most part only affected by the target depth-to-size or "D/S" ratio. By "size" we mean the intermediate dimension of the body, either strike or depth extent. Generally, a D/S ratio of 2: 1 is within the sensitivity range of the UTEM system. By contrast, with the pulse systems, the response amplitude is not only adversely affected by increasing the D/S ratio of the target, but also by an increase in the time constant (T) of the response decay. Recall that the anomaly decay of a more conductive target has a larger value of T than does a poorly conductive target. As a consequence, with a pulse system the better conductors, which are often massive sulphide bodies, are harder to see at depth than the less conductive (or less massive) ones!

This may be illustrated using an example. To start with, we assume that both systems have the same electronic sensitivity. If the target of interest is a vertical tabular body with dimensions (A x A) and a conductance (conductivity x thickness) such that the time constant is about 1 ms, the UTEM and pulse response amplitudes would be about the same for a typical sampling interval; ergo Q = 16 (Figure 2). In normal noise conditions, it would be possible to detect such a body at a depth of about 2·A. If, however, this body were ten times more conductive, its time constant would be ten times larger. In this case, the UTEM amplitude would be largely unchanged (the anomaly would only be shifted later in time), ***however the pulse amplitude would be reduced to about one tenth its original value.*** To bring the anomaly amplitude up to its "detectable" amplitude, the target depth of burial would have to be decreased to A/2. In other words, the maximum "depth of penetration" for the pulse system would be about 1/4 that of the UTEM system.

The use of TEM borehole techniques to get around the problem of depth penetration would appear to make these kind of system sensitivity differences less important, since the sensor is so much closer to the target. However, real-life target decays are much more complex than the simple, single exponential decay considered in this comparison; they are comprised of a spectrum of decay modes. A system which biases one mode of decay over another makes interpretation of the anomaly unnecessarily difficult. Also, TEM borehole techniques are often used to pinpoint massive sulphide targets in the vicinity of weaker, "stringer" mineralization. The short time constant decays due to such mineralization tends to dominate the response of a pulse system making discrimination of the main ore zone difficult or impossible. In short, the system with a uniform system sensitivity over the range of possible decay time constants provides a more straight-forward interpretation of the anomaly and a greater chance of discriminating significant mineralization.

For more information, visit
www.lamontagnegeophysics.com



Inset: The UTEM receiver can also be configured to measure electric fields to produce resistivity sections.

Inset: UTEM crew on the hunt for VMS, Pyrite Belt.

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