Fast TEM for UXO mapping at Gambell, Saint Lawrence Island, Alaska

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Abstract

A fast-sampling, Transient Electromagnetic (TEM) system was assembled for mapping probable UXO submerged in a shallow fresh-water lake near Gambell, Saint Lawrence Island, Alaska. The survey was designed to generate optimal data given the survey area, UXO characteristics, and the required depth of exploration. Since the search area was a fresh-water lake in an arctic climate, the survey was conducted in early May. The lake ice was still sufficiently thick to provide safe access, but most of the snow cover had melted, making it easy to move equipment across the search area. A continuous-sampling TEM system that records averaged data every three seconds was mounted on a sled and towed at a slow walk by the equipment operator. A real-time differential GPS unit recorded the sled's location every five seconds.

Using this system, a total of 426,000 line-feet of profile with an average sample interval of 7.5 ft were surveyed over a period of 14 days. At each sample point, vertical-component transient data were recorded at 26 delay times, ranging from 7 to 570 microseconds. In this paper, we describe in detail the design of the antenna system and the survey. Area maps of the TEM response at several gates are presented. Using the maps and transient profile plots, target locations were picked. Analysis of the transient decay curves observed over the targets provides additional information about target size and conductivity.

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Introduction

During clean up of an early-warning-radar facility in the early 60's, a sled-load of small arms rounds in ammunition boxes was reportedly dumped into the northern end of Troutman Lake. Troutman Lake is a shallow fresh-water lake just south of Gambell, on the Northwest Cape of Saint Lawrence Island, Alaska (figure 1). Due to the arctic climate of region, thick ice covers the lake until mid-June. Taking advantage of the climate, a TEM survey using sled-mounted equipment was conducted in May 2000, while the ice was still 1.5 m thick, but most of the snow cover had melted and 18 hours of daylight extended the potential workday.

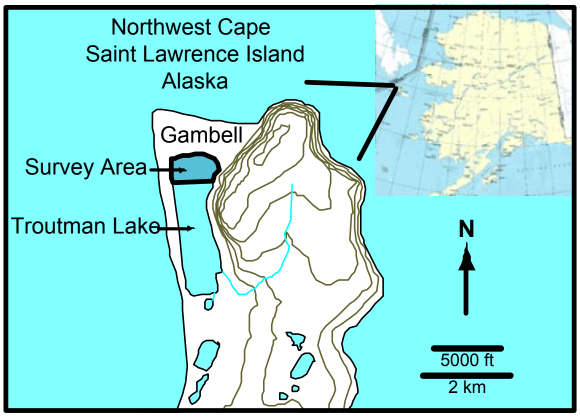

Figure 1: A sled mounted TEM system was towed across the ice to map UXO under the northern end of Troutman Lake.

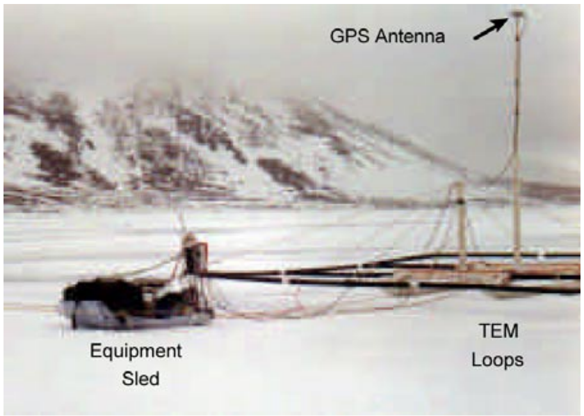

Figure 2: A sled mounted TEM system was towed across thick lake ice in May 2000. A real-time differential GPS system recorded accurate positions. TEM transients were recorded at 26 times spaced logarithmically between 7 and 570 usec.

Although the original sled-load of stacked ammunition boxes was a large conductive mass, other UXO characteristics are possible. Large breakers churn across Troutman Lake during fall storms, so the ammunition may now be in separate ammunition boxes scattered across the lake bottom, or even dispersed as individual small-arms rounds. The unusual survey environment and range of possible UXO characteristics controlled both the TEM equipment configuration and survey parameters.

Survey Design

Thick ice cover made it easy to tow sled-mounted equipment across the ice (figure 2). Averaged TEM transients were recorded every 3 seconds using an in-loop TEM configuration. A real-time, kinematic-phase differential GPS unit kept track of the sled's position as it was towed along line by the equipment operator and recorded positions accurate to better than 0.1 m every 5 seconds.

Spatial Sampling Requirements

The northern end of Troutman Lake is fairly shallow, 2 to 3 m deep across the center of the search area. As the half-width of an in-loop TEM anomaly is proportional to target depth (Nabighian and Macnae, 1987), a sampling interval of 2 m along line generated two to three anomalous points over detectable targets (figure 3). A 7.6 m (25 foot) line spacing was used over the entire survey area, with 3.8 m (12.5 foot) line increments across the more crucial central search area (figure 4).

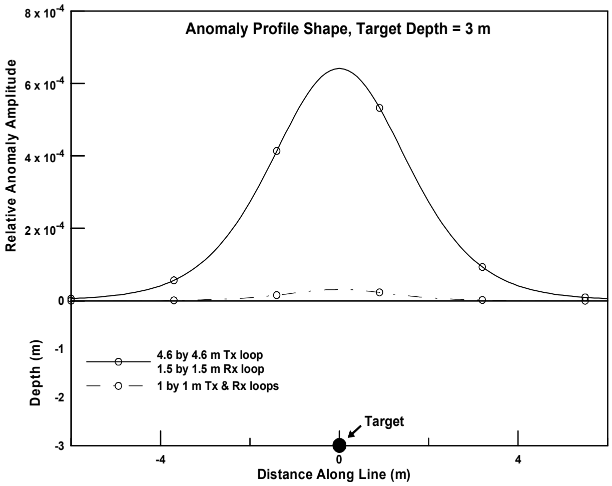

Figure 3: TEM profiles over a compact conductive object have a positive peak with a half-amplitude width proportional to target depth. Objects on the bottom of a 3 m deep lake will generate anomaly peaks that are about 3 m wide. A TEM system using large loops (solid line) is more sensitive to targets at a depth of 2 m than a system using small loops (dashed line).

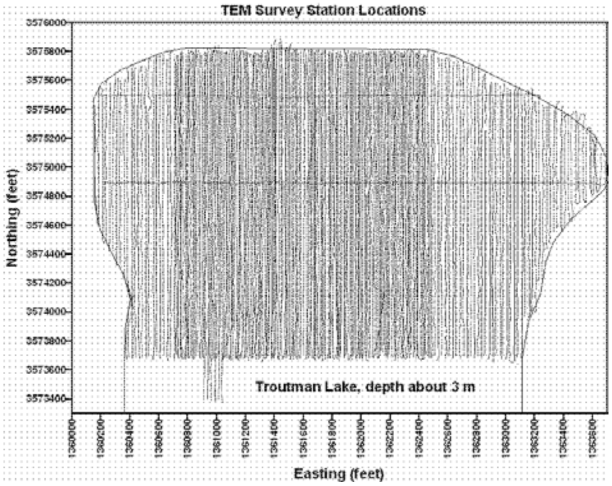

Figure 4: Readings were recorded every 2 to 2.5 m (7.5 feet) along line, sufficiently close to map anomalies from objects on the bottom of the 2 to 3 m deep lake. Lines were spaced a minimum of 7.6 m (25 feet) apart, with 3.8 m (12.5 feet) line intervals over the center of the survey area.

Background-geology TEM responses have smooth spatial variation, while UXO TEM anomalies are compact positive peaks. The contrast allows suppression of background-geologic responses by spatial filtering.

Time Sampling Requirements

Transient data were recorded at 26 delay times spaced logarithmically between 7 and 570 microseconds (usec). Recording a complete transient waveform provides several advantages. Compact metallic conductors produce a TEM signal dominated by an exponential decay, exp(-t/τ), at later transient delay times (Kaufman, 1978). Target size and conductivity control the time constant (τ). Larger and more conductive objects have larger characteristic time constants. Recording full transients saves sufficient information for time-constant estimates, returning useful information about UXO properties.

UXO exponential time constants control the optimal transient delay time for target detection. The exponential-decay signal from UXO is masked by a geologic-background TEM response which decays in proportion to t^{-k}, where $k = 5/2$ for a uniform half-space and can vary between 3/2 and 7/2 over layered-earth backgrounds (McCracken, et al, 1986) (figure 5). UXO signals are most detectable when the target/background response ratio is at its maximum, which occurs at delay time = $k \cdot \tau$. Different size search objects have different time constants, consequently no single transient delay time is optimal in searching for UXO with a wide range of sizes.

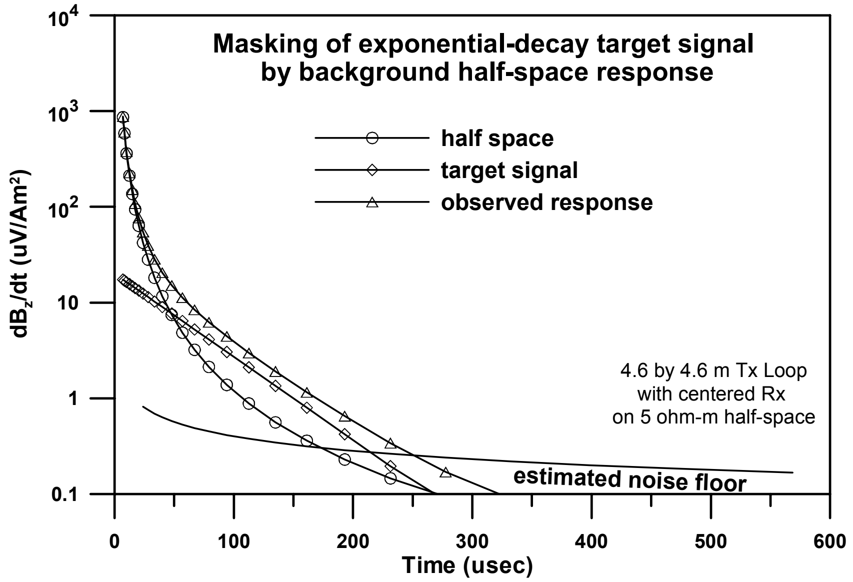

*Figure 5: Transient values were measured at 26 delay times ranging from 7 to 270 usec. TEM data include a geologic background response, which decays in proportion to t^{-k}, with $3/2 < k < 7/2$. Signals from UXO targets are dominated by an exponential decay, exp(-t/τ), which makes a straight line with slope -1/τ on log-linear transient plots. Geologic background masks exponential target responses at early transient delay times. UXO signals are most detectable relative to geologic background at transient delay times of k*τ.*

Loop Size

Optimal TEM loop size is controlled by expected UXO depth. Small 1 by 1 m loops are optimal for the detection of shallow objects. However, the 1 to 3 m depth to UXO on the bottom of Troutman Lake increases the optimal loop size. Plotting peak anomaly amplitude versus TEM loop size (figure 6) shows a relationship between UXO depth and optimal loop size. For UXO 0.5 m below the loop, peak anomaly amplitude reaches a maximum for 1.2 by 1.2 m loops. When the UXO depth is increased to 2 m, 5 by 5 m loops are optimal, although practical considerations put an upper limit on loop size. Our 4.6 by 4.6 m transmitter loop was near optimal size, and yet was small enough to construct as a light sled-mounted structure. Using a smaller 1.5 by 1.5 receiver loop improved the early-time characteristics of the TEM system at the cost of reduced late-time signal amplitude.

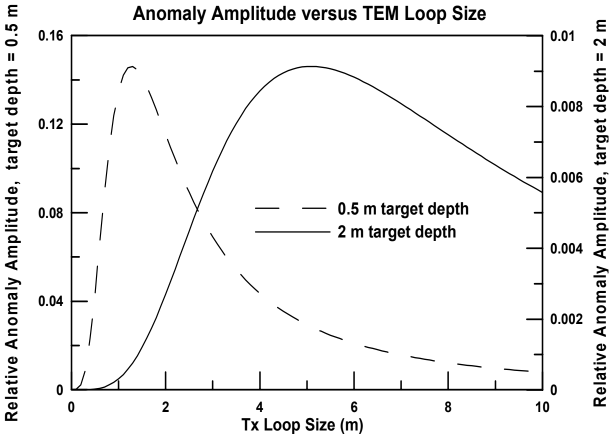

Figure 6: Optimal loop sizes increase with increasing target depth. Targets 0.5 m below the TEM system produce maximum anomaly amplitudes in 1 by 1m loops. 5 by 5 m loops are optimal for 2m target depths.

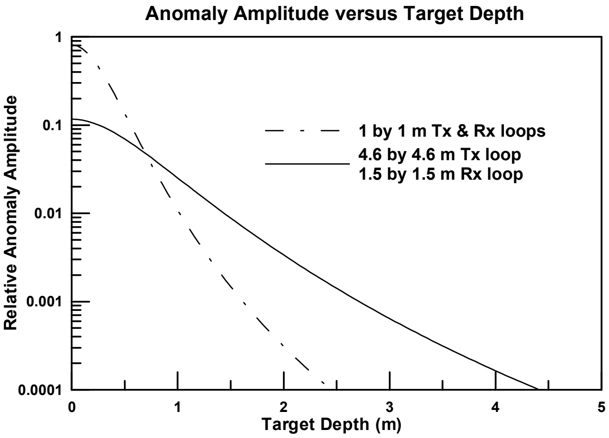

Figure 7: A TEM system using a 4.5 by 4.5 m transmitter loop is more sensitive to targets at depths of 0.8 m or greater than a system using 1 by 1 m loops. Conversely, for shallow targets a system using small loops is nearly 8 times more sensitive to near-surface objects.

Using larger TEM loops does sacrifice sensitivity to near-surface targets. Figure 7 shows anomaly amplitude versus target depth for 1 by 1 m and 4.6 by 4.6 m loop TEM systems. Using larger loops reduces the system's sensitivity to near-surface objects by a factor of 8 relative to a 1 by 1 m loop system, but a large loop system has relatively more sensitivity to objects at depths more than of 0.8 m.

Survey Results

A 2000 by 3400 foot area over the northern end of Troutman lake was mapped with 426,000 line-feet of profile data. Twenty-eight targets were selected using both profile and plan map data presentations. A plan map of 40 usec data (figure 8) shows narrow target anomalies superimposed on a smoothly varying geologic-background response. A profile view along a line through Anomaly C (figure 9) shows how the response of a strong target anomaly stands out from geologic background.

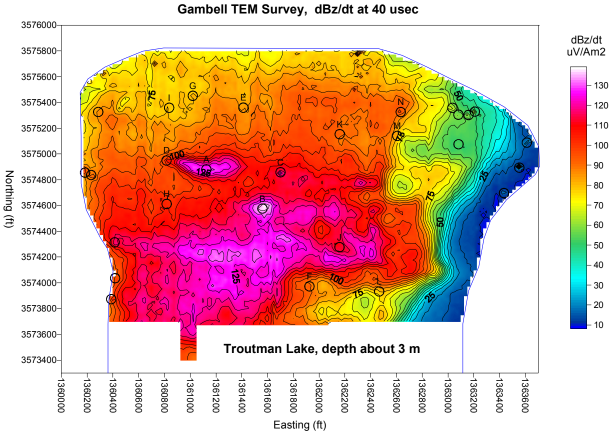

Figure 8: Plan map of 40 usec TEM data showing compact target anomalies superimposed on a smoothly varying geologic background response.

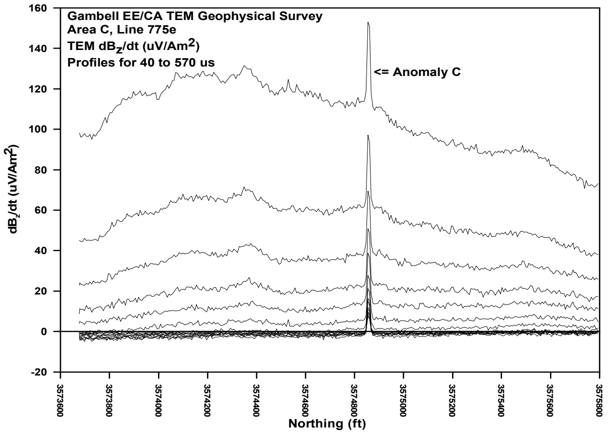

Figure 9: TEM profiles across Anomaly C, a sharp spike that stands out from the more smoothly varying geologic-background response.

Analysis of a transient from Anomaly C (figure 10) shows how a large conductive object produces a strong late-time anomaly dominated by a single exponential decay. Exponential decay forms straight-line segments on log-linear plots of dBz/dt versus time. Line slope is proportional to the exponential time constant. The target signal from Anomaly C indicates a 410 usec time constant, consistent with a conductive object the size of a 55 gallon drum. In contrast, Anomaly B (figure 11), has a 20 to 80 usec target signal with a much shorter time constant, 14 usec, indicative of a smaller conductor.

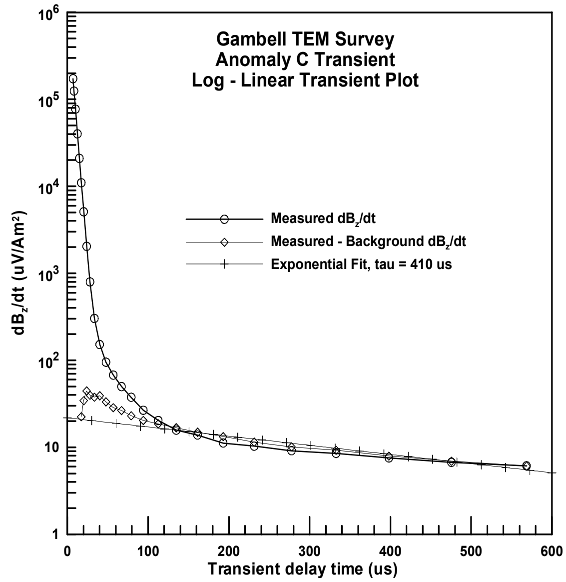

Figure 10: A log-linear plot of a transient from the peak of Anomaly C, shows a straight-line exponential decay from 100 to 570 usec. A target time constant of 410 usec is estimated from a straight line fit to late-time data.

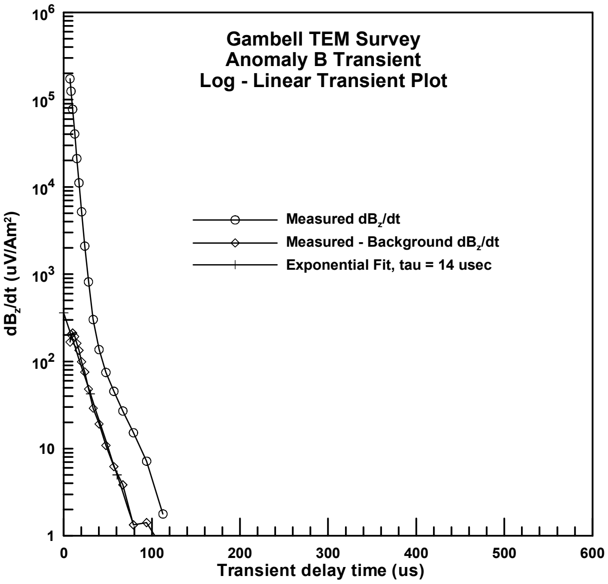

Figure 11: A log-linear plot of a transient from the peak of Anomaly B, shows a straight-line exponential decay between 20 and 80 usec. Slope from a straight-line fit indicates a target time constant of 14 usec.

Conclusions

No single equipment configuration is optimal for all situations. Survey results can be optimized by adjusting both equipment design and survey parameters. Larger loops improve TEM's sensitivity to deeper objects, at the cost of portability and sensitivity to shallow UXO. The optimal time window for UXO detection in the presence of a background geologic response is proportional to the target's dominant exponential time constant, a function of target size, shape and conductivity. Recording a full transient waveform allows UXO detection using more than one time window when searching for a range of UXO types. Analysis of full-transient data can produce information about the target's size, shape and conductivity.

References

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