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TECHNICAL NOTE TN-16

CORRECTION OF MEASURED TRANSIENT ELECTROMAGNETIC RESPONSES FOR FINITE TRANSMITTER TURN-OFF DURATION

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INTRODUCTION

The decay curves measured with a transient electromagnetic (TEM) system such as the Geonics EM37 depend on the shape of the transmitter (TX) current waveform. Ideally this waveform consists of a series of alternating, bipolar, rectangular current pulses of equal mark/space ratio, with infinitely fast transmitter current turn-on and turn-off times. The EM37 transmitter departs from this ideal in two respects:

(1) The current turn-on is exponential; however this does not usually affect the measured transient.

(2) More importantly the current turn-off is a closely controlled linear ramp of finite duration t_o. In this case the emf induced in free space, being proportional to the time derivative of the primary flux and thus the transmitter current, is a rectangular pulse rather than the true delta function which would be the case for t_o=o.

This technical note describes an algorithm for converting the measured TEM response generated by a rectangular pulse emf to the corresponding "impulse response" which would have been obtained if the drive duration (TX turnoff time) was vanishingly small. The algorithm also provides, to within an additive constant, the response obtained if the drive emf was an ideal step function, as would be induced if the triangular TX waveform of the UTEM system was used. As discussed further in Geonics Technical Note TN-12, this "step response" corresponds to the time integral of the impulse response: i.e., if the measured impulse response is dB(t)/dt then the step response is B(t). In fact the algorithm operates by first calculating B(t) from the measurements, and then differentiating to provide $\dot{B}$ = dB(t)/dt.

Note however that this algorithm does not provide any correction for "runon" effects, which occur when responses are still large at times of the order of the repetition period.

ALGORITHM

The algorithm will be developed for the particular case of logarithmically spaced gates. It is based on the fact that the measured response F(t) for a system which uses a linear ramp turn-off is related (after correction for system gain) to the step response B(t) by the formula

$$F(t) = [B(t) - B(t+t_o)] / t_o \quad (1),$$

where F(t) is taken at a time t after the end of turnoff, and t_o is the turn-off duration.

The process begins with an estimation of the value of B(t) at the last gate B_N. This estimate might be made, for example, by assuming a particular decay law for B(t) for times later than the last gate (possibly derived from the behaviour over the last few gates) and then integrating from $t=\infty$ to the time of the last gate. Any error in this value is propagated as a constant error in B for all earlier gates; however, its importance usually decreases rapidly as the measured amplitudes increase at earlier times; furthermore the error has no affect at all on the values of $\dot{B}$.

The algorithm continues by estimating values for $B(t+t_o)$ at progressively earlier gates as described below, which then allows B(t) to be determined using equation (1). When the turn-off time is less than the separation between the gate being evaluated and the next later gate (i.e., for the later gates), $B(t+t_o)$ is estimated using the value of B already calculated for the next later gate, and also the measurements of F at the two gates as approximations for dB/dt. When the separation between the gates is less than the turnoff (i.e., for earlier gates) $t+t_o$ falls between gates for which B has already been estimated, and $B(t+t_o)$ is estimated by interpolation. Finally, when all B's have been calculated, dB/dt is evaluated by numerical differentiation.

The algorithm may be summarized as follows:

i) Estimate $B_N = B(t_N)$ by assuming some particular decay law for $t>t_N$

ii) For progressively earlier gates k, estimate $B(t_k') = B(t_k+t_o)$ using equation (2a) if $(t_k'<t_{k+1})$ or equation (2b) if $(t_k'>t_{k+1})$,

then evaluate $B(t_k)$ using equation (3)

iii) When all $B(t_k)$ have been evaluated, $\dot{B}(t_k)$ is determined by differentiation of B using equation (4)

The formulas used are:

$$B(t_k+t_o) = B\ (t_k')$$

$$= B\ (t_{k+1}) + (t_{k+1} - t_k') * (a_o\ F_k+a_1F_{k+1}) \quad \text{if } t_k'(=t_k+t_o)<t_{k+1} \qquad (2a)$$

$$= B\ (t_{\ell+1}) + X * [Q_1\ D_1 + Q_2\ D_2 + X* (Q_3D_1+Q_4D_2)] \quad \text{if } t_\ell<t_k'<t_{\ell+1};\ell>k \qquad (2b)$$

$$B(t_k) = B(t_k') + F_k * t_o \qquad (3)$$

In the above formulae, which assume gates spaced so that $R=t_{k+1}/t_k$:

F_k is the measurement for gate k after calibration,

$X = (t_{\ell+1} - t_k')/t_\ell$

$Q_1 = R/\ (R^2-1)$

$Q_2 = 1/[R(R^2-1)]$

$Q_3 = 1/[(R-1)\ \ (R^2-1)]$

$Q_4 = -Q_3/R$

$D_1 = B_{\ell+1} - B_\ell$

$D_2 = B_{\ell+2} - B_{\ell+1}$

Final differentiation is carried out with an approximation of the form:

$$\dot{B}_k \cong [a\ B_j + b\ B_{j+1} + c\ B_{j+2}]/[2t_k \log_e(R)] \qquad (4),$$

where $j = 1$, $k=1$ (1st gate)
$= N-2$, $k=N$ (last gate)
$= k-1$, (intermediate gates)

Constants a,b, and c in equation (4) are different for the first, intermediate, and last gates. Suitable values were determined by requiring equation (4) to give exact results for three different representative decay laws. The performance of the resulting operator was then evaluated for a range of different decay laws by comparing their computed responses with the exact theoretical responses. During this procedure a_0 and a_1 were also empirically selected for the best fit. The results are discussed below.

ACCURACY

For carrying out reductions on Geonics EM37 data, for which the gate spacings correspond to $R=2^{1/3}$, the numerical constants used in equations (2a) and (4) were selected to be

a_0, a_1 = 0.35, 0.65;
a, b, c = 3.32, - 4.59, 1.27 $k = 1$
= 3.4 , - 0.69, -2.71 $k = N$
= 0.843, 0.287, - 1.13 otherwise

With these values, it is found that for power law decays in B ranging from t^0 to t^{-4}, the correction is accurate to 3% or better for all gates as shown in Figure 1.

SUMMARY

It is possible to convert measured TEM responses, generated using a TX waveform which turns off with a linear ramp of significant duration, to idealized impulse responses corresponding to instantaneous turn-off. An algorithm has been outlined which, in addition to providing with good accuracy the corrected impulse response, also gives the corresponding step response which would be obtained with a triangular TX waveform, although subject to some offset.

While the procedure is probably not faster in computation than would be possible using a deconvolution filter based on Fourier transforms, it has the advantage that the constants used are independent of the ramp turn-off duration.

ACCURACY OF TURNOFF CORRECTION
FOR POWER LAW DECAYS: t_o=300μs

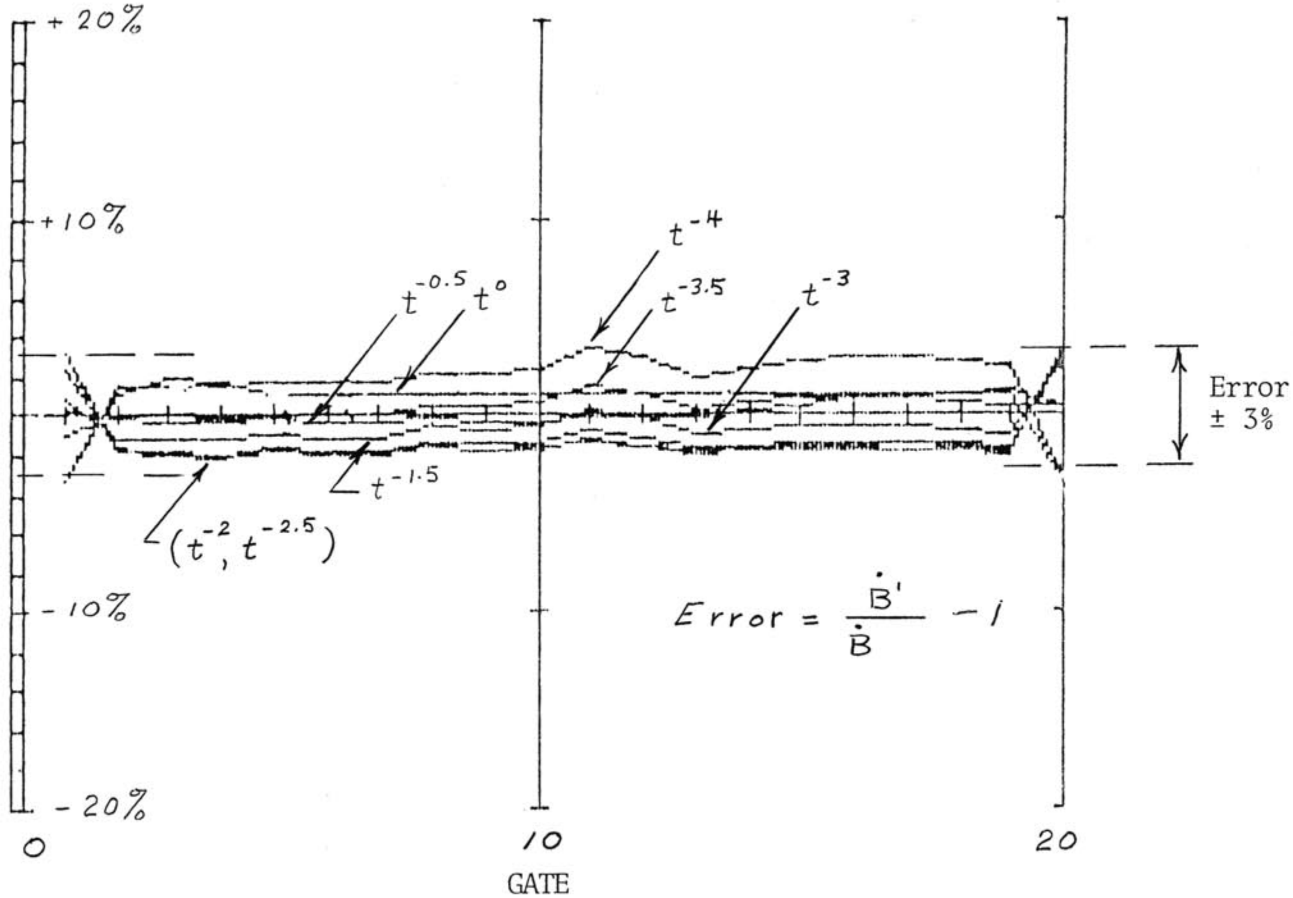

FIGURE 1