Interpretation of out of loop data in large fixed-loop TEM surveys

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Summary

Interpretation of out-of-loop data from fixed-loop transient EM surveys can be enhanced by using plate models. Numerical modeling shows it is possible to distinguish flat-lying conductors from vertical conductive sheets by comparing the appearance of the vertical and along-line out of loop measurements. Where multiple, steeply-dipping conductive sheets exist, the sheet nearest the transmitter may diminish the responses of more distant sheets, but will usually not cause the more distant sheet to be undetectable. Screening increases with closeness of adjacent plates and with increasing conductance. If the screening effect is not taken into account, estimates of conductance, and by inference, ore tonnage, may be underestimated

Introduction

In complex geological scenarios, conditions may exist whereby more than one conducting sheet is encompassed within the surveyed area (Figure 1). Transient electromagnetic surveys employing large fixed loop transmitters have been used for wide area reconnaissance, and in such situations it is reasonable to ask how multiple conducting sheets would appear in the out-of-loop data collected in these surveys. Modeling shows that the conductive sheet closest to the transmitter has a screening effect on the amplitude of anomalies produced by more distant, but otherwise identical conductive sheets, beyond the falloff produced simply by increased distance from the transmitter. This is true for both the vertical (Z) and the along-line (X) components of the transient response. More unexpected is that the magnitude of the anomaly of the proximate conductor is also decreased by the presence of the more distant conducting sheet. We also see that when two conductive sheets are close together, the X component of the transient response is a better discriminator of two conductors than is the Z component. In cases where the two conductors are near one another, there may be no crossover from positive to negative in the vertical component.

Method

The first step in interpreting out-of-loop data is to make a qualitative assessment of the anomaly based on the shape of the X- and Z-component transient decay curves. Curve shape varies considerably depending on whether a conductor is flat-lying or vertical (Nabighian and Macnae, 1991).

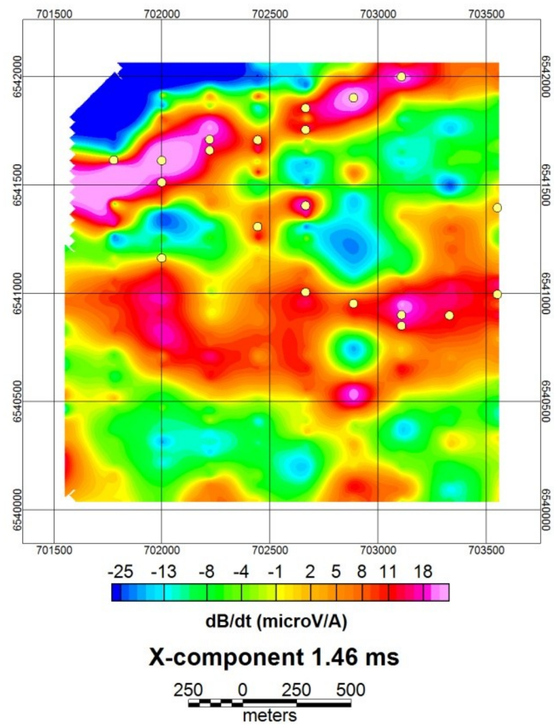

Figure 1: dBx/dt anomalies for multiple conductors. Yellow circles indicate Z-crossovers. Large loop transmitter is north of survey area.

Figure 2 shows the difference in the responses of a horizontal conductive plate and one that is vertical, as computed by ZPLATE, a code which models a thin conductive plate in an otherwise resistive earth. The modeled plate is 400 m long (parallel to the long edge of the transmitting loop) and 200 m wide/deep. Its depth of burial is 50 m from the surface. Its thickness is infinitesimal, but it has a 20 S conductance. The plate is located 1200 m from the near edge of a 2000 m x 1000 m transmitting loop. The modeled response shown is for 2 ms. The horizontal plate produces a large dBz/dt negative response and a positive-to-negative dBx/dt response, whereas the vertical plate has a positive-to-negative dBz/dt response and a positive dBx/dt anomaly directly over the plate.

The data in Figure 1 indicate at least two steeply-dipping conductors, one in the north part of the survey area trending east-northeast, and another trending east-west through the central part. Both have prominent Z-crossover anomalies (yellow circles) in addition to the X-component peaks. But is there a third conductor sandwiched between the two, shielded from responding by the conductors on either side?

To address this, we used the LEROI code which allows modeling of multiple conductive plates in a layered earth. The model used was a two-layer earth with a 30 m thick, 20 ohm-m layer overlying a 1000 ohm-m lower layer. The vertical conductive plates are identical and are completely within the lower layer, but extend to the interface with the top layer. The vertical plate's conductance is 100 S. The plates are 400 m apart at 800 m, 1200 m and 1600 m from the front edge of the 2000 m x 1000 m transmitting loop (to the left of the plot). Shown in Figure 3 are transient decays from 5.1 ms to 12.4 ms. The center plate has an obvious anomaly, indicating that the level of shielding is not extreme, and therefore, the minor anomalies between the two major bands of anomalies in Figure 1 are inconsistent with the presence of a third conductor. (Note: In this study, the X-component response from LEROI was multiplied by -1 in order to produce a positive peak over conductors.)

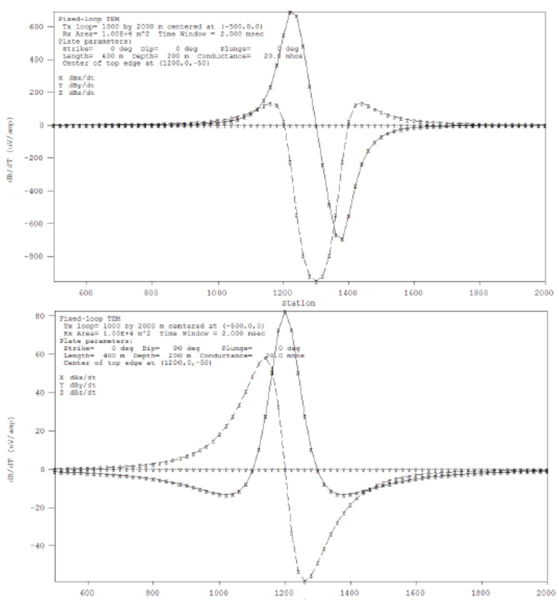

Figure 2: Different responses for horizontal (top) and vertical (bottom) conductive plates. Transmitting loop is on the left side.

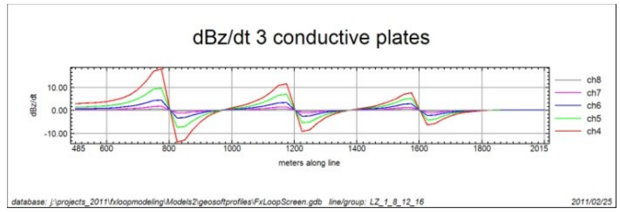

Figure 3: dBz/dt anomalies from three identical vertical conductors separated by 400m.

The question remains as to what degree of shielding takes place. Using LEROI and the same layered earth model, we computed the responses of three separate models, having single 100 S conductors located at 800m, 1200m, and 1600m. Table 1 shows the peak-to-peak anomaly from channel 4 (5.1 ms) for the three conductor case and the single conductor models.

Table 1. Three vs one conductor Z responses (σt=100 S)

Location	Single Plate	Three Plates	Pct Diff
800m	32.67	31.83	2.6
1200m	22.24	20.82	6.4
1600m	14.92	13.95	6.5

Table 1 reveals that the single plate response is larger than the three plates together, even for the plate nearest the transmitting loop. However, the amount of shielding is marginal, no more than 6.5% for any given plates.

We performed the same analysis with plates having a smaller conductance, 20 S instead of 100 S. Table 2 shows that even though responses are smaller, the amount of screening is still no more than 5%. As an aside, we note that these anomalies had small "negative" lobes, and some of them failed to go below zero. If an interpreter is looking for Z-crossovers, such anomalies may be overlooked because they fail to go negative, or do so only weakly.

Table 2. Three vs one conductor Z responses (σt=20 S, 400 m separation)

Location	Single Plate	Three Plates	Pct Diff
800m	2.95	2.88	2.4
1200m	2.98	2.83	5.0
1600m	2.66	2.56	3.8

In the previous models, the plates were 400 m apart. If the separation is narrowed to 200 m, the shielding effect is enhanced, partly from superposition of the anomalies, as shown in Figure 4. Table 3 shows that the degree of shielding has increased to more than 13%. However, even in this more extreme case, the central plate still produces a strong, easily detectable anomaly.

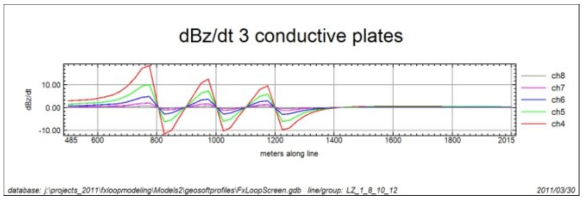

Figure 4: dBz/dt anomalies from three identical vertical conductors separated by 200m.

Table 3. Three vs one conductor Z responses (σt=100 S, 200m separation)

Location	Single Plate	Three Plates	Pct Diff
800m	32.67	30.03	8.1
1000m	26.93	22.82	9.1
1200m	22.24	19.30	13.2

The X-component response for the 800m-1000m-1200m model is shown in Figure 5, and the shielding effect is listed in Table 4. The X-component appears to be shielded somewhat less than the Z-component (Table 3), but that is partly because of superposition effects. If the positive X-component peak is taken without regard for the negative lobe, the shielding is increased, as shown in Table 5.

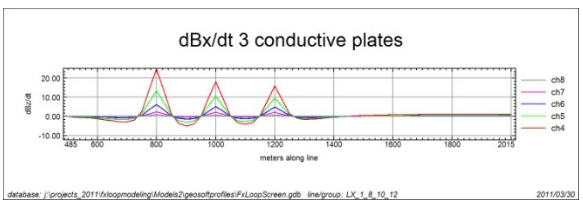

Figure 5: dBx/dt anomalies from three identical vertical conductors separated by 200m.

Table 4. Three vs one conductor X responses with superposition (σt=100 S)

Location	Single Plate	Three Plates	Pct Diff
800m	30.14	27.91	7.4
1200m	24.81	22.27	10.2
1600m	20.49	19.98	2.5

Table 5. Three vs one conductor X responses, positive peaks only(σt=100 S)

Location	Single Plate	Three Plates	Pct Diff
800m	28.10	24.69	7.9
1200m	23.45	18.10	22.8
1600m	19.63	15.81	19.5

To simulate actual field parameters we modeled a rectangular loop that was 2000 m x 1000 m. The long edge of the rectangle was perpendicular to the survey lines, and parallel to the strike of the conductive plates. We computed the peak response of the Z- and X-components for a single 100 S plate at varying distances from the loop center (Figure 6). The falloff in response with distance for the Z component and the X component are nearly identical. The decay exponent for the dBz/dt is 1.7 and for dBx/dt, 1.6. The low falloff exponent is a result of the large loop size (Parasnis, 1991).

We compared the responses shown in Figure 6 with the responses of a shielded plate in a two-plate model. We adjusted the location of the second plate so that it was 100, 200, 400, 600, 800, and 1000 m from the first plate. Figure 7 shows the shielded response for the X-component and Figure 8 shows shielding for the Z-component. In both cases, the shielding has become small, only a few percent, by the time the plates are 400 m apart. When the plates are less than that distance, the shielding effect may exceed 20%. When the plates are very close together, the shielding may be enhanced by superposition whereby the proximate sheet's negative lobe cancels the more distant sheet's positive anomaly, distorting the Z-crossover. Figure 9 illustrates this effect with two vertical sheets separated by only 100 m. The negative lobe of the first sheet and the positive lobe of the second are barely visible. In real data, and anomaly such as this easily could be interpreted as a single body. Drilling vertically at the "Z-crossover" would produce a dry hole, as the ore bodies would be on either side. In such circumstance, the X-component might be the best data set from which to interpret as the peaks may be preserved despite superposition (Figure 10).

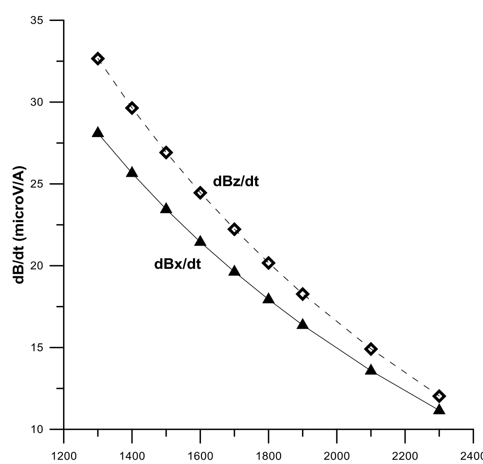

Figure 6: Z- and X-component anomalies for a 100 S plate at varying distances from the transmitting loop center.

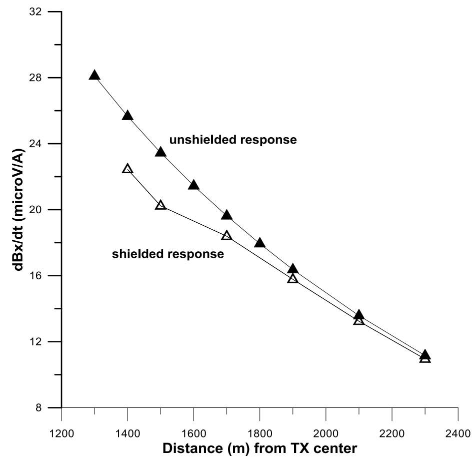

Figure 7: X-component anomalies for a single 100 S plate at varying distances from the transmitting loop center (unshielded) and the shielded anomaly of the second plate of a two-plate model.

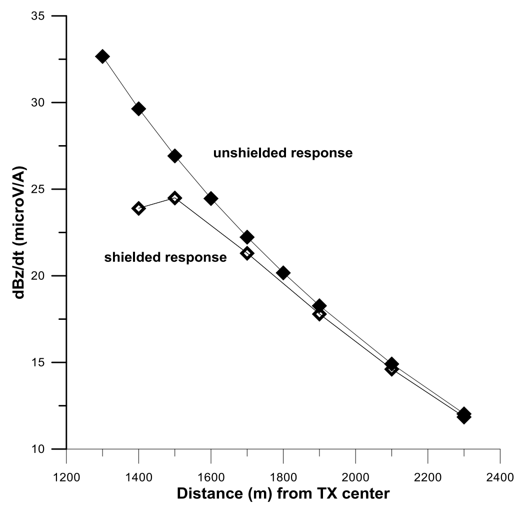

Figure 8: Z-component anomalies for a single 100 S plate at varying distances from the transmitting loop center (unshielded) and the shielded anomaly of the second plate of a two-plate model.

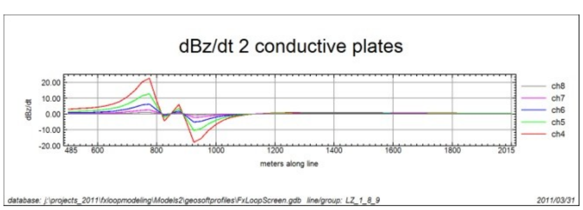

Figure 9: Z-component anomalies for two 100 S plates spaced 100 m apart. Superposition causes the positive lobe of the second plate to be small.

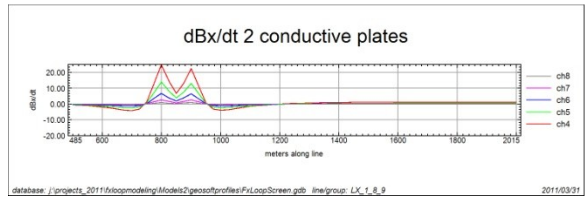

Figure 10: X-component anomalies for two 100 S plates spaced 100 m apart. Two anomaly peaks are still clearly seen.

Conclusions

Numerical modeling is useful in obtaining a better understanding any set of geophysical data, but it is indispensible when the particular data type is infrequently encountered. With out-of-loop TEM data, the extra information obtained by having both Z- and X-component data was well worth the marginal extra cost in obtaining two components rather than one. With the out-of-loop data encountered in this field study, modeling helped us determine whether the conductors were flat-lying or vertical, and helped in understanding the degree of screening that might be taking place, and how superposition can effect interpretation of Z-component data by obscuring the expected crossover. We also were able to rule out a third conductor sandwiched between the two conductive bands. The level of screening increases as plate conductance increases and as plates get closer to one another. Although screening may diminish an anomaly's response only marginally, if not taken into account it can reduce the estimate of conductance and by inference, ore grade or tonnage.

Acknowledgments

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EDITED REFERENCES

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