Summary

The increased signal-to-noise of a SQUID B-field TEM sensor over dB/dt induction coils, which are more commonly used in TEM surveying, provides an advantage for survey optimization that can help reduce the cost of a SQUID survey and make SQUID more complete with induction coils, even though the costs of a SQUID sensor is many times the cost of an induction coil. Reducing transmitter loop size and increasing station interval are two simple procedures that result in lower survey costs, but do not seriously adverse the interpretability of the data because of the greater increase in signal-to-noise provided by SQUID. Offset moving-loop or Slingram survey procedures, popular in the Athabasca Basin for uranium exploration, can be further simplified, and made more cost effective, by reducing transmitter-receiver separation, which results in higher resolution data for interpretation, and by surveying two lines from a single transmitter loop.

Introduction

A SQUID is a Superconducting Quantum Interference Device, which is utilized in transient electromagnetic (TEM) surveying as a B-field sensor. It provides higher signal-to-noise TEM data than a dB/dt induction coil at the low frequencies commonly utilized in TEM surveying. Reduced noise TEM data, particularly at low frequency, leads to greater depth of exploration and especially the detection of deep basement conductors under conductive cover and within moderately conductive host rocks. Reduced noise TEM data also leads to a more accurate interpretation using forward modeling and inversion techniques, and hence more confidence in selecting specific targets for follow-up drill tests.

In addition to these well known and practiced advantages of SQUID B-field TEM over induction coil dB/dt, there is another class of benefits that hasn’t been as fully exercised. Because the signal-to-noise of SQUID B-field TEM data is better than induction coil dB/dt data, certain survey procedures can be simplified to increase the efficiency and reduce the cost of TEM surveying. These survey “shortcuts” do not appreciably reduce the detection and interpretation effectiveness of SQUID TEM, but they can reduce the overall survey costs to the point where SQUID TEM is no more expensive than using a standard induction coil, in spite of the significant difference in the cost of these two different types of sensors.

Figure 1: Late time, anomalous SQUID B-field response (vertical component) over a 750m deep conductor using an 800m by 800m transmitter loop (top) and a 400m by 400m loop (bottom). The conductor dips shallowly to the left with its top edge close to the position of maximum gradient. Note that the anomaly using the smaller transmitter loop has about 25% the amplitude of the larger loop, as expected, but that the signal-to-noise is comparable: i.e. adequate for an interpretation by modeling or inversion.
Optimizing Transmitter Loop Size

A prime example of how TEM surveying can be simplified using a SQUID sensor is by reducing transmitter loop size, as shown in Figure 1. If a loop is reduced by half (e.g., from 800m square to 400m square), then the primary field is reduced to 25%, and for most situations, the secondary response is reduced a like amount. However, the signal-to-noise of SQUID data is commonly an order of magnitude greater than induction coil TEM data, so even with the reduced primary signal from a reduced transmitter loop size, the SQUID data are still significantly better than induction coil. In addition, it is often possible to increase the current in a smaller loop, because of its reduced resistance, and also to double the turns because a smaller loop is more manageable in the field, and gain back some of the primary field reduction.

Reducing loop size does not make too much difference to the efficiency and costs of a fixed-loop survey (some but not much), but it does make a tremendous difference for a moving-loop TEM survey, either centre in-loop or offset Slingram type surveys. Fewer personnel are required on the survey crew and the transmitter loop can be moved from station to station much quicker.

Optimizing Station Interval

Another TEM survey “shortcut” that can be applied without serious loss of data quality and integrity, because the signal-to-noise of SQUID is better than induction coil, is to increase the reading interval along the survey line, as shown in Figure 2. Small station intervals are required if the spatial wavelength of the secondary fields are small, for instance from shallow conductors. But SQUID TEM is primarily applied for deep exploration and there is less concern that spatial variability of near-surface conductive cover will alias the results, because SQUID B-field minimizes low-conductivity response and maximizes the anomaly from deep high-conductivity targets.

Small station interval is also useful in a normal induction coil TEM survey simply to increase the number of readings over an anomaly and hence reduce the effect of noise contamination, especially when the data are interpreted by forward modeling or inversion. However with SQUID TEM, the order of magnitude increase in signal-to-noise results in better and more interruptible data, even if half the stations are recorded. Reducing the readings by a factor of two will significantly increase the productivity and reduce the costs of a fixed-loop TEM survey.

Figure 2: Fixed-loop TEM data (horizontal component) over two conductors at about 500m depth using a 1200m by 800m transmitter loop. The conductors are located beneath the response maximums. The negative to positive cross-over is due to a layered-earth response centered on the transmitter loop. The SQUID data (top) were collected at 100m station interval. The induction coil data (bottom) were collected at 50m station interval, primarily to insure sufficient data for an interpretation, when the data are noisy. Note the much clearer definition of two conductors with the SQUID data even though they were collected with half the station density.
Optimizing Slingram Survey Design

Other survey simplifications can be realized using an offset moving-loop or Slingram type TEM survey. For instance, it makes little difference to the anomalous response from a long conductor, whether the SQUID receiver is positioned on a line bisecting the loop, or on a line extending from the side of the loop. But the later arrangement is easier and less costly to carry out because fewer survey lines need to be cut and chained in forested areas. Also, by utilizing two SQUIDs and receivers, two lines can be surveyed simultaneously with each Slingram survey, thereby doubling the cost effectiveness of this survey mode. The same survey efficiency can be realized with a center or in-loop, moving-loop TEM survey by utilizing a rectangular transmitter loop and placing two SQUIDs and receivers on two lines straddled by the loop.

Offset distance from the transmitter loop to the SQUID receiver in a Slingram TEM survey can also be minimized to make the survey easier to carry out and reduce the length of lines that need to be cut and chained. As shown in the model results in Figure 3, at less than a certain distance, proportional to the depth of investigation (i.e. roughly 150%), the amplitude of anomalous response begins to decrease from the maximum obtained at a distance equal to twice the depth of the conductor. But again, this modest reduction in amplitude is not a major concern for a SQUID TEM survey because the signal-to-noise of the anomalous response is an order of magnitude greater than for an induction coil TEM survey. And in addition to the marginally reduced line cutting costs from a smaller transmitter-receiver separation, the resultant narrowing of the anomaly is advantageous for interpretation, especially for the resolution of multiple conductors.

Acknowledgements

The following companies are thanked for the data examples: Anglo American PLC, AREVA Resources Canada Inc., Cameco Corp., CanAlaska Uranium Ltd., and Denison Mines Corp. The author is indebted to Lawrence Bzdel (Cameco), Tiaan Le Roux (Anglo), Guy Marquis (CanAlaska), Larry Petrie (Denison), and Joseph Roux (AREVA) for arranging release of the data. Andreas Chwala and Frank Bauer from the Institute of Photonic Technology (IPHT) are thanked for their continued SQUID R&D and technical support. Hans-Georg Meyer (IPHT) and Matthias Meyer (Supracon AG) are thanked for continued business support.

Figure 3: Offset moving-loop (Slingram) SQUID TEM model results for a simple vertical conductor in a layered earth. The depth to the top of the conductor is 600m. The Slingram survey geometry is a double-turn 400m by 400m transmitter loop with the SQUID receiver at 1200m (top), 800m (center) and 500m (bottom) from the center of the transmitter loop. Vertical component in red and horizontal component in blue. Note the slight reduction in anomaly amplitude with decreasing receiver-transmitter separation but the more significant increase in resolution.