A multiple transmitter/receiver system: the advantage of summing responses from multiple transmitters

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Summary

Many ground electromagnetic (EM) systems have been deployed in the Sudbury basin and under ideal conditions these systems are capable of detecting large conductors to depths of approximately 800m; however, more common detection limits are in the order of a couple of hundred meters (<400m). Although these systems have had great success in Sudbury, they may experience two weaknesses for deeper conductors: poor coupling and small signal-to-noise ratios, decreasing the quality and interpretability of the data. A time-domain electromagnetic survey was conducted over a known conductor to test a new methodology, which could potentially see deeper targets. The coupling weakness was addressed through multiple transmitter locations and the signal-to-noise ratio was increased above the noise threshold by spatial stacking of receiver measurements (from the various transmitter-receiver combinations).

Introduction

As shallower mineral deposits become scarcer, the need for new techniques and methods will become essential to discover deposits at greater depths. Within the Sudbury Basin, EM plays a significant role in discovering Ni-Cu-PGE deposits in the Sudbury Igneous Complex (SIC) as well as within the footwall and the offset dykes. To discover deposits that are deeper, a transmitter configuration is needed that will excite currents within them. Often this is accomplished using a larger transmitter loop as the magnetic field will be stronger at depth and hence will provide an increased depth of penetration (Spies, 1989). However, issues with coupling still occur. For example, to couple to a vertical body the transmitter must be moved away from the body and this reduces the strength of the field at depth. Without knowledge of the depth, geometry and orientation of the conductor, a single large loop may not always provide good coupling. This issue has been partially addressed by the InfiniTEM system, which utilizes a dual loop configuration similar to that suggested by Spies (1975). However, if this loop is not properly placed, issues with coupling may still occur.

Another potential method to see deeper targets is through longer acquisition times. Often, currently available EM surveys use a single receiver that is moved between stations. The receiver only takes measurements at the station for a short period of time before being moved to the next location. However, recent reductions in the cost of receivers and advances in distributed array technology allow multiple receivers to be deployed at once. This means that the acquisition time at each station is significantly longer (hours compared to minutes or seconds). Data collection over longer intervals allows the reduction of noise, increasing the signal-to-noise ratio.

We are proposing a survey methodology that uses multiple transmitter and receiver locations. By combining data from a multiplicity of transmitters we can ensure coupling issues are minimized. Data from multiple transmitters and receivers can be further combined to enhance the signal-to-noise ratio. We do not have multiple receivers and/or a distributed array acquisition system, but an ultimate goal of this research is to suggest how the data could be collected more efficiently if one was available.

Method

A test site was selected with a target at approximately 70m depth in the Sudbury Basin. The small, vertical, thin deposit consists of massive to patchy pyrrhotite, hosted in an area of felsic and mafic metavolcanics. This is not a deep target, but it was an easily accessible target that could be used for experimenting with procedures that could be used to look for deeper targets.

The time domain survey was carried out over a one kilometer line at a station spacing of 25m, with the deposit located in the middle of the line. The survey was completed using a Geonics TEM57-MK2 transmitter, two 10m by 10m loops (with 10 turns) and two receiver teams each using a SMARTemV receiver equipped with a Geonics 3D induction coil. The current waveform was a square wave with a peak amplitude of 20 Amps and the base frequency was 30Hz.

To test the concept of using multiple transmitters to improve coupling, the transmitter was placed at the stations occupying the inner 600m of the line, accounting for 25 transmitter positions. Figure 1 is a simplified schematic of the survey line, showing fewer transmitter and receiver positions than there were in reality. Since the location of the mineralized zone was known, these positions were chosen to simulate locations that would both couple well and poorly. At each transmitter position, two receiver teams would each survey half of the corresponding line, so that together the whole line would be surveyed. Then the transmitter was moved to the next location and the receiver teams repeated the measurements of the survey line. This

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procedure was repeated until all 25 transmitter locations had been occupied. Using two transmitter loops reduced survey acquisition time since the unused loop could be positioned at the next station while the other loop was active as the transmitter. Binding ten parallel wires together meant that all ten turns could be laid out at once. This meant that loop deployment was easier in areas with thick vegetation and rugged terrain.

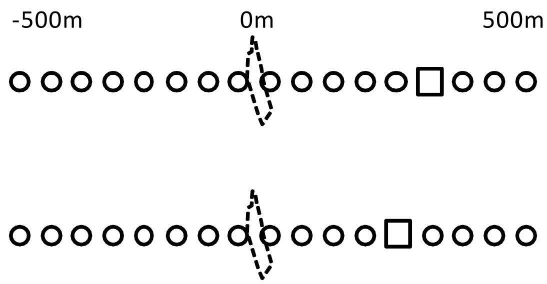

Figure 1: Simplified schematic plan view of survey logistics. Rectangles represent the transmitter position; circles the receiver positions and the dashed line represents the outline of the ore body at approximately 70m depth. In reality there were 42 receiver positions and a total of 25 transmitter positions. Receiver measurements were recorded every 25m while the 25 transmitter positions only occupied the inner 600m of the survey line.

In this paper we investigate the consequences of combining the measurements at a particular receiver location from one transmitter with the measurements at the same receiver location and one or more other transmitters. Doing so can raise the signal of a subsurface conductor above the noise threshold and allow it to be detected. This was demonstrated using different transmitter combinations that simulated larger single loops as well as other configurations such as the InfiniTEM configuration. Our transmitter locations were only along one traverse; if there were transmitter positions off-line, there will be a larger number of possible transmitter combinations.

Results

Using multiple transmitter locations ensures that some of the transmitters will couple well with the body regardless of the location of the body in the subsurface. For example, in Figure 2, absolute coupling coefficients (normalized by the peak amplitude) were calculated as a function of transmitter offsets for a 50 m deep vertical conductor located at three locations on the profile, 100 m, 0 m, and -100 m. In all three scenarios, the body and the transmitter are null coupled when the transmitter is directly over the body. However, as the transmitter offset is increased, the response is elevated to a point of maximum coupling about 25 m away, followed by a decrease in coupling with larger offsets. In this example, placing the transmitters every 100 m at (-300, -200, … 300) would only give coupling coefficients of about 0.1 or zero, a poor result. However, choosing transmitter positions every 50 m (-300, -250, … 300) would ensure coupling coefficients of greater than 0.6 at more than one location for each conductor. This is a much better result.

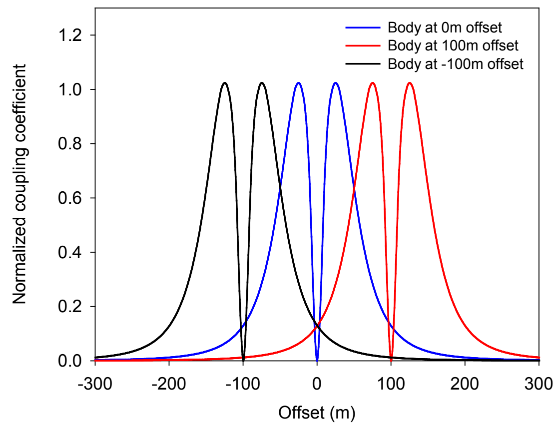

Figure 2: Calculated normalized coupling coefficients (Z component) for transmitter offsets with respect to a vertical body at a depth of 50m. The blue line represents a body at 0m offset, the red at 100m offset and the black at -100m offset. Above the body the transmitter is null coupled, but with offset increasing maximum coupling is achieved at ±25 m followed by a decrease in coupling with larger offsets.

Through reciprocity tests and by estimating the magnitude of geometric errors, the total noise for each measurement location was estimated to be about 0.01µV/A or less. The responses at one receiver location for one transmitter can be added to the response at the same receiver location for a second transmitter, to give the response that would be obtained if a larger transmitter were used. Figure 3 shows a profile with one transmitter at location +300 and another profile when receiver measurements from multiple transmitter measurements are added.

When the transmitter is at +300, the response of the body is just evident above the noise level on this line, which appears to be about 0.005 µV/A. The response falls below the noise by window 6, so that the decay is interpretable up to 0.2950 ms. The signal-to-noise ratio at 0.1910 ms (window 4) is 1.11. Windows 1-3 were not plotted as the data may have been corrupted due to poor sampling or transmitter ramp effects. The area with no data represents removed corrupted data where the receiver was in close proximity of the transmitter. The response obtained by summing the response from three transmitter positions from +300 to +250, gives a signal-to-noise ratio of 3.86 at 0.1910 ms and the decay remaining above the noise to window 10, giving an interpretable decay until 0.7005 ms.

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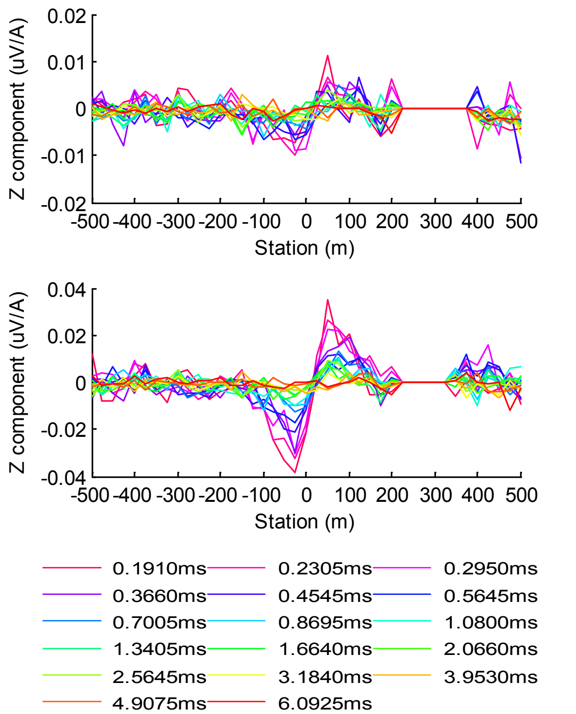

Figure 3: The amplitude of the response plotted as a function of receiver position. The top panel is for a transmitter at location +300 and bottom panel shows the summed response from three transmitter locations between +300 to +250.

The increase in the signal-to-noise ratio for this process is dependent on the number of transmitter positions summed and the coupling of each transmitter. With more transmitter positions summed together, the response is accentuated with respect to the noise. Figure 4 shows how the sum of 5 adjacent transmitter locations (+300 to +200) that are both well and poorly coupled can simulate a larger loop; accentuating the response from the body. The response obtained by summing the response from five transmitter positions from +300 to +200, gives a signal-to-noise ratio of 6.98 at 0.1910 ms and the decay remains above the noise up to window 11, giving an interpretable decay until 0.8695 ms.

However, if the measurements are the result from a poorly coupled transmitter, then the measurement will not contribute greatly to the sum. However, many poorly coupled positions are still of value as they may elevate the response above the noise envelope. Figure 5 shows how the transmitters at the ends of the line can contribute and result in a stronger response from the ore body. Alone the anomaly in each transmitter is difficult to interpret, but together the response becomes larger compared to the noise. When the response from transmitted locations +275 and -275 are summed, the signal-to-noise ratio is 2.6 at 0.1910 ms and the decay remains above the noise up to window 8, giving an interpretation interpretable decay until 0.4545 ms.

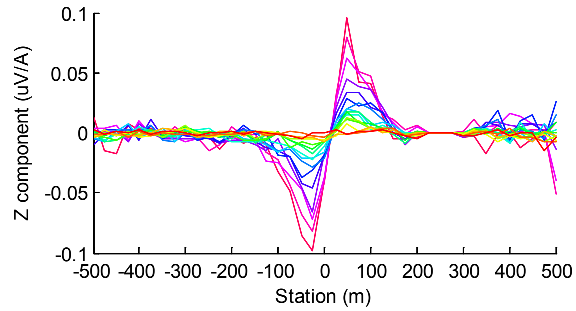

Figure 4: The amplitude response plotted as a function of receiver position for transmitter locations +300 to +200

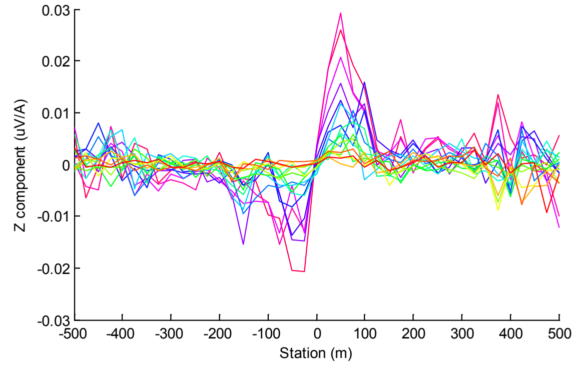

Figure 5: The amplitude response plotted as a function of receiver position for transmitter locations +275 and -275.

If the dip of the body were different, different combinations would give a stronger signal-to-noise ratio. For example, a horizontal thin sheet, would give a maximum response by summing the transmitters directly above the body. If the sheet is vertical, then transmitters on either side of the body will couple in opposite ways, so subtracting the receiver responses from these opposite transmitters will enhance the response. This is equivalent to having the current in the transmitter flowing in opposite directions around the loop, which is essentially what happens in the InfiniTEM configuration used by Abitibi Geophysics. Figure 6 shows how transmitters on either side of the body can be combined in an InfiniTEM configuration as to significantly increase the response from a vertical conductor. When the receiver response from transmitter positions +75 to +150 are summed and then subtracted from the sum of transmitter positions -75 to -150, the signal-to-noise ratio is 144 at 0.1910 ms and the decay remains above the noise up to window 20, giving an interpretable decay until 6.0925 ms.

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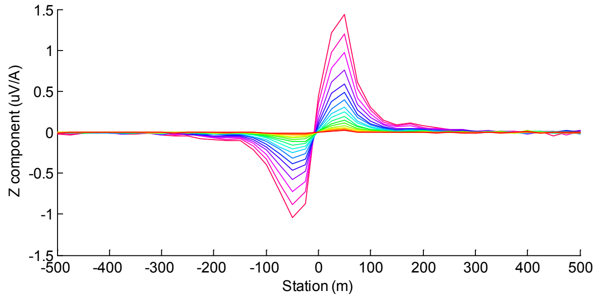

Figure 6: The amplitude response plotted as a function of receiver position obtained from summing the responses for transmitter locations +75 to +150 and subtracting the sum from locations -75 to -150.

With multiple transmitter locations, the body can be excited from many different locations, both online and offline. Exciting the body from multiple orientations and analyzing the different responses can reveal geometric information about the body, such as strike and dip. Furthermore these offline transmitter positions would provide additional excitation and when added to the sum, would further increase the signal-to-noise ratio. This is equivalent to having a larger transmitter loop extending either side of the survey line.

Further work

Another aspect we are looking to investigate is whether it is possible to sum the response at receiver locations to further enhance the response from deep conductors. Finally, if multiple distributed array receivers are used, the receivers could be laid out for hours rather than minutes, reducing the survey time and increasing the signal to noise ratio. These two improvements should allow a multiple transmitter and receiver system to increase the signal-to-noise ratio to see deeper targets, providing a viable solution to discover mineralization at greater depths, or smaller more subtle bodies.

Conclusions

As shallower deposits become scarcer, there is a strong need to devise a new methodology to discover conductive ore deposits at greater depths. Using a system with multiple transmitter and receiver locations, the signal-to-noise ratio of a response can be elevated and observed to later delay times, resulting in more interpretable data. In one example the signal to noise ratio was increased by a factor of 6.5 by increasing the transmitter loop area by a factor of 5. When eight transmitter loops are used in a configuration similar to the InfiniTEM configuration, the signal-to-noise ratio at comparable times was 144.

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EDITED REFERENCES

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