Field trials of the Biassed Heterodyne Method of Exploration for Sulphide Minerals

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SUMMARY

Theoretical investigation and laboratory testing indicate that it may be possible to detect buried sulphide deposits by utilising non-linearity of electrical conduction between semi-conducting sulphide grains. In these tests, the method of detection of the non-linear conductivity effects relies on the heterodyne principle whereby two frequencies will mix to give intermodulation sum and difference frequencies in the presence of non-linear conduction.
Field tests of the method were run over known mineralisation at the Kempfield deposits 180km west of Sydney. Two modified Induced Polarisation transmitters were used in a gradient array configuration. Signals were detected using custom built receivers incorporating both 24-bit and 31-bit analog-to-digital converters.
Significant logistical problems were encountered due to a number of factors including interference from one transmitter on another and possible interference in the receiver circuitry. The transmitter to transmitter interference precluded trialling the use of a DC bias to emphasise any non-linear mixing terms. Evidence of the interference between transmitters highlighted the need for careful checking that the intermodulation effects are not arising within the electronic circuitry rather than from the earth.
The data gathered in the field trial is confusing in that it has obvious problems with signals that are not related to the desired effects. However, when approximate corrections for these are made, a pattern emerges that is correlated with the known sulphide distribution and Induced Polarisation responses.
It appears that the heterodyne method has detected sulphide mineralisation at Kempfield but there are many obstacles to overcome before this can routinely be used for exploration.

Key words: Non-linear conduction, heterodyne method, sulphide exploration, Kempfield

INTRODUCTION

The last geophysical technique in exploration for sulphide minerals that was developed using a new physical property of those minerals, was the Induced Polarisation (IP) technique prior to World War 2. The Simple Heterodyne (SH) and Biassed Heterodyne (BH) techniques may be the next.

It has long been known that some or all sulphide minerals are semiconductors, Shaub, (1965) and Katsube et al., (1973) and that junctions between the semiconducting grains are likely to conduct in a non-linear fashion in terms of the potential across the grain boundary versus the current through it. The best known example of this was the use of galena crystals as diode detectors in early radio receivers (J.C. Bose 1858-1939). The authors believe that the bulk presence of such non-linear conducting junctions within a sulphide deposit may be used as the basis for a new exploration technique using this intrinsic property, which is different to all other common geophysical techniques currently in use. The technique has some promise for the discrimination of different sulphide minerals but before these details can be considered it is necessary to show that the effect can be observed in the field. Preliminary field trials of the techniques involved is the subject of this study.

Early work by White (1974) and more recently by Oertel et al (2018) (this volume) indicates that the non-linear conduction can be observed in laboratory tests on core samples and that different types of sulphide minerals and graphite may respond differently.

We believe that the bulk occurrence of non-linearly conducting grain boundaries may be detectable by using the heterodyne principle whereby two frequencies of electrical signal are injected into the ground in a similar fashion to standard IP/Resistivity surveys and the sum and difference (intermodulation) frequencies detected using a grounded receiver dipole, again similar to the IP method. Intermodulation frequencies should only be generated where the electrical conduction is non-linear in current with respect to potential. The non-linearity may arise either at sulphide grain junctions or possibly as part of the electrochemical reactions that produce IP signals. These field trials are designed to test whether this occurs in sulphide deposits only, in all minerals, or not at all.

If only two primary frequencies are used, the method is referred to here as Simple Heterodyne (SH). Theoretical and laboratory tests suggest that the magnitude of the intermodulation frequency signals can be enhanced by applying a direct current (DC) bias to the rocks to slightly shift the operating position on the potential/current curve to a possibly more non-linear point. The application of this property is referred to as the Biassed Heterodyne (BH) method. The field trips discussed here had intended to trial this (BH) technique but logistical and equipment problems prevented the investigation of this hypothesis in the field. Thus, only Simple Heterodyne results were obtained. Further SH and BH trial surveys are planned.

The field tests detected intermodulation frequencies but were compromised by a series of equipment and systemic problems. Results of the tests show a coherent variation in these secondary signals but also contain a number of artefacts that complicate the results. We believe that these tests have detected the heterodyne signals but further work is needed to clarify the results to the point where they could be used routinely in exploration for sulphide deposits.

METHOD

The field tests were conducted at the Kempfield polymetallic sulphide occurrence which lies approximately 180 kilometres west of Sydney near the town of Trunkey Creek. The geology and mineralogy of the Kempfield deposits have been documented by Timms and David (2011) and more recently by McGilvray (2017). The Kempfield deposits are of the volcanic hosted massive sulphide (VHMS) type in interbedded felsic volcanics and sediments of Silurian Age. The deposits are primarily silver and barite deposits but there are many zones of polymetallic sulphides. The area chosen for the SH and BH tests is an area of known sulphide mineralisation which has numerous drill intersections, known as the McCarron Zone. Core samples for this area were taken for laboratory testing of the non-linear properties but results for this work is not available at the time of writing this paper.

The object of the field tests was to determine if the mixing frequencies could be detected in the field and whether these data are related to known zones of sulphide mineralisation. Several key factors in the execution of these trials had to be decided upon prior to the site visits. Some of these factors are listed below.

The frequencies to be used may be critical to the detection of the mixing signal resulting from inter-grain sulphide junctions. There is little prior information that could help in making the decision as to what these frequencies should be. It is not even clear at this stage whether the primary and mixing signals should be in the range of units, 10's or 100's of Hertz. Mitchell and Russell (1980) used frequencies of 0.02 and 0.065 Hz in their surveys which were designed to investigate non-linearities in the sulphide grain to groundwater interface rather than in grain to grain junctions. A decision was made to use primary frequencies lower than 100 Hz to avoid electromagnetic considerations as far as possible. Very low frequencies such as were used by Mitchell and Russell will produce results weighted towards non-linearity due to electrochemical effects. The primary frequencies were chosen such that the difference mixing frequency (f1-f2) lies at the minimum in atmospheric noise between telluric and spheric influences at about 30 Hz. Somewhat controversially, one of the primary signals was chosen to lie at 50 Hz which is the local power transmission frequency. This was chosen on the basis that the powerline frequency may present a problem in the recording of the mixing terms and that by using this as one of the primary signals the powerline noise would be completely overwhelmed by the transmitted signal. There is still discussion as to whether this was a valid assumption. This then led to the second primary frequency being chosen to be 80 Hz. Thus the primary frequencies used are 50 and 80 Hz and the two main mixing frequencies are at 30 Hz (f1-f2) and 130 Hz (f1+f2).

It was decided that the two primary signals and also the bias signal, if used, should be injected into the ground at separate contact points. This meant that for each transmitter location, three wires and six electrode locations were required. While this led to a considerable increase in effort in the field it is felt that the high current densities that surround each transmitter electrode could be a significant cause of extraneous signal if both frequencies were present in the high current density zone immediately surrounding the transmitter electrodes. Mitchell and Russell (1980) report spurious non-linear effects arising from using common grounding electrodes for two frequency investigations. In future trials, it is envisaged that the need for using separate transmitter contact electrodes will be tested using a source capable of simultaneously generating two transmitter frequencies. If this proves possible, the logistical difficulties involved in running these surveys would be considerably reduced.

Since the two primary frequencies were injected at separate locations and it was desirable for the two primary signals to be approximately equal in magnitude over the area of investigation, the gradient array configuration was chosen for the trial survey such that the area of investigation was within the area of relatively uniform current density between the transmitter electrodes. This also minimised the number of transmitter electrodes necessary for the test.

The question of the transmitter waveform was decided on a practicality and budget basis. Ideally, pure sine waves would be used for the primary signals. The preferred bias waveform is a castle type waveform, similar to that used in a standard time domain IP survey. The rationale for the bias waveform was that the secondary signals could be examined during the positive bias pulse, the off time and the negative pulse and a comparison of these would provide information as to the effectiveness of using a bias to enhance the effect. This waveform is routinely used in time domain IP surveys, so should have been relatively easy to produce using a standard IP transmitter. It was also considered that the difference in mixing signal between the bias on pulse and the off pulse may be used as a method to reduce external noise. In the long run it may be possible to measure IP effects at the same time as a BH survey using this bias waveform. Despite the desire for pure sine wave primaries, square wave signals were significantly easier to produce due to the availability of existing IP transmitters which could be cheaply modified to produce the desired frequencies. The transmitters used in these trials were modified Zonge IP transmitters outputting square waves. This choice was made due to budgetary and time constraints but in the longer term, there will be significantly less complications if sine wave primary signals are used.

Any mixing signals detected are likely to vary across the spread of the survey area due to the relatively large variations in the local resistivities of the rocks in the survey area. In order to minimise the effects of resistivity variations, mixing signals were normalised by the primary signals at the receiver locations. It is still not clear whether this is valid, as the very non-linearity of the process suggests that the effect may vary in a different way to the primary signal. However, it was necessary to minimise the effects of local resistivity on the received signal so a parameter was developed that normalises the mixing signals by the primary. The secondary signals were expected from laboratory tests (White, 1974 and Oertel et al., 2018) to be between three and four orders of magnitude lower than the primary signals so the parameter used in these tests is the amplitude of the mixing term divided by the average of the received primary signals multiplied by 1000. This is referred to here as "Mixability". There are several mixability terms depending on which of the intermodulation frequencies are recovered. That is, there is a difference mixability (f1-f2) and a sum mixability (f1+f2) and also higher order mixing terms.

At the time of writing this paper, two field trials have been run over the Kempfield deposits. Figure 1 shows the layout used for the second trial. A Zonge GGT-30 was used for the 80Hz signal and a Zonge GGT-10 for the 50Hz signal. Both the transmitters were adjusted to output 5 amps of current. The controllers for these instruments have been modified such that they produced square wave signals at the appropriate frequencies. The bias transmitter was to be a GDD TxII IP transmitter but, unfortunately, this transmitter would not function while the transmitters for the primary signals were operating. It was assumed that the internal circuitry for the GDD transmitter detected the signals from the primary transmitters and shut itself down, assuming an internal fault.

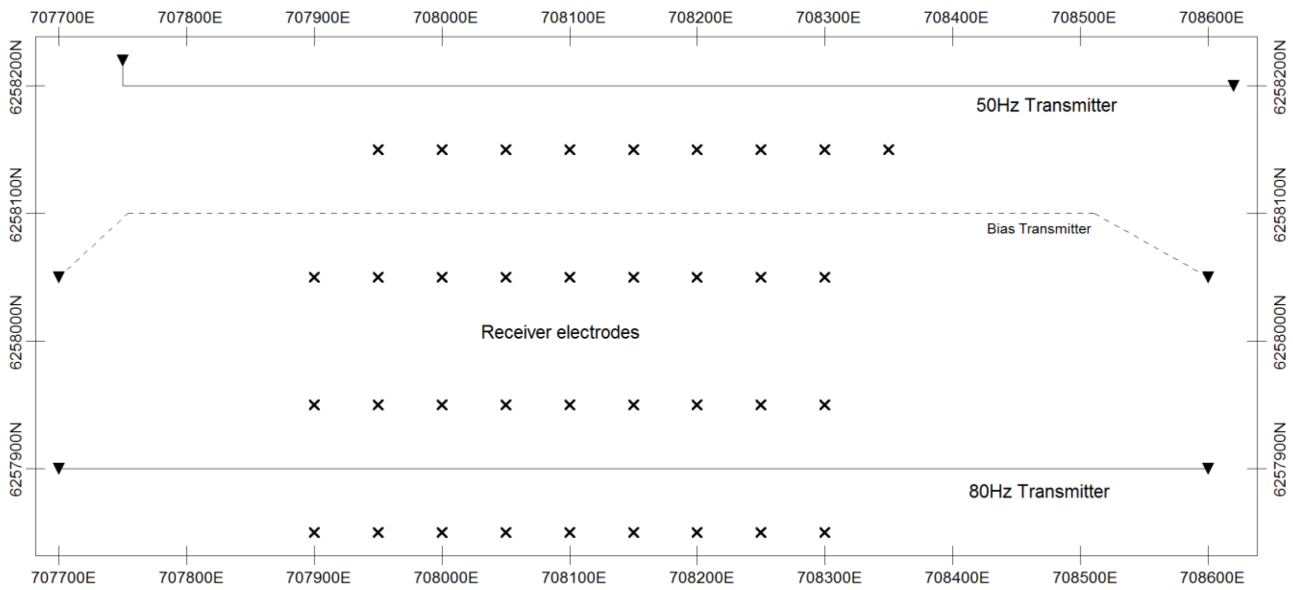

Figure 1 Layout for field trials of the Biassed Heterodyne Method at Kempfield, NSW.

The receiver consisted of a 50m electric dipole which was traversed along the lines at 50 metre intervals. The received signal was passed through a low noise, high impedance, unity gain differential amplifier and then to either a National Instruments 24-bit analogue-to-digital converter (ADC) or a 31-bit ADC based on a Texas Instruments evaluation board. The ADC converter output was captured and analyse by custom software. These were the same receiver configurations as used by Oertel et al. (2018) for laboratory testing. Results for the 24-bit ADC were found to have lower resolution and a higher noise floor than the 31-bit ADC but there appeared to be some noise artefacts of unknown origin within the 31-bit data. The 24-bit data were found to be adequate for these tests as the results from both systems were very close in form and amplitude. Only the 24-bit data are considered here.

RESULTS

The first trial surveyed only one line of 400m length as most of the time in the field was spent trying to get the transmitters functioning correctly. Following the failure of the bias transmitter due to interference, the outputs from the two primary transmitters were measured to see if any interference was occurring between these. The waveform of the currents being produced by these was measured and analysed. Within the output waveform for each transmitter, mixing frequencies were detected at about the same amplitude relative to the fundamental frequency amplitude as would be expected at the receivers over sulphide occurrences. We assume that for each primary transmitter a small amount of signal from the other transmitter was leaking into the circuit through galvanic and/or EM coupling means. This leakage from the other transmitter would be mixed within the transmitter circuitry such that some of the desired mixing frequencies contaminate each of the primary signals. Though this is a significant problem, we considered that these spurious signals would cause a broad relatively uniform background in the mixability data that should be readily distinguished from signals due to buried sulphides. For the first trial, the transmitter wires were close together and care was taken in the second trial to separate the transmitter wires as much as possible to reduce EM coupling between the transmitters. Examination of the waveforms at the receiver location showed the EM coupling from the transmitters to the receiver (Figure 4) to be significantly less in the second trial so we assume that the transmitter to transmitter coupling is also reduced.

Results for the first field program are shown in Figure 2. Only one line was surveyed but the partial correspondence of the mixability values with the location of the known sulphide bearing rocks was sufficient to justify further field testing.

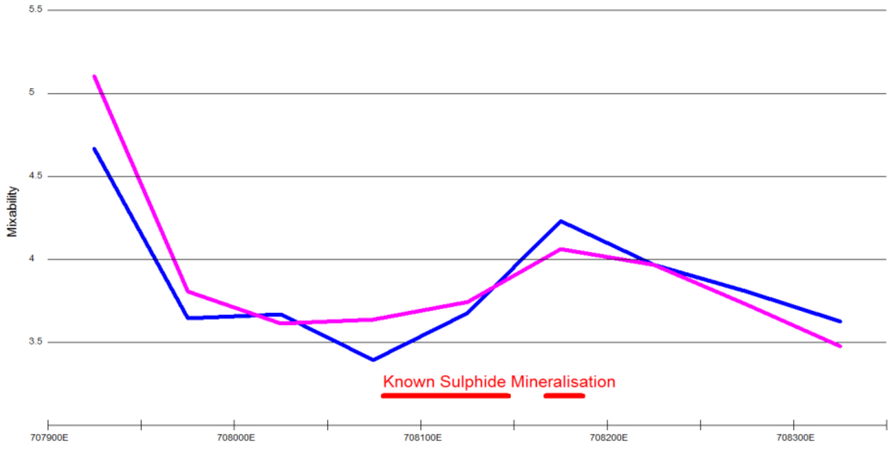

Figure 2 Profile of mixability on line 6,258,050N from first field trial (with repeated readings)

The second field test covered the same area as the first test with four lines being surveyed to determine if the possible response measured in the first survey followed the known trends in the sulphide mineralisation. A Phoenix IP transmitter was to be used for the bias signal but again it failed to operate, due to instrument malfunction. As a result, at the time of writing this abstract, no field tests have been undertaken on the effect of DC bias on the system. Four lines of SH data were collected, approximately centred on the possible response detected in the first trial. 24-bit and 31-bit ADC results are similar, as are the results for both sum and difference mixability parameters. Only 24-bit sum mixability results are shown here as this is typical of all the measurement types. Figure 3 shows a plan map of the raw sum (f1+f2) mixability for 24-bit ADC.

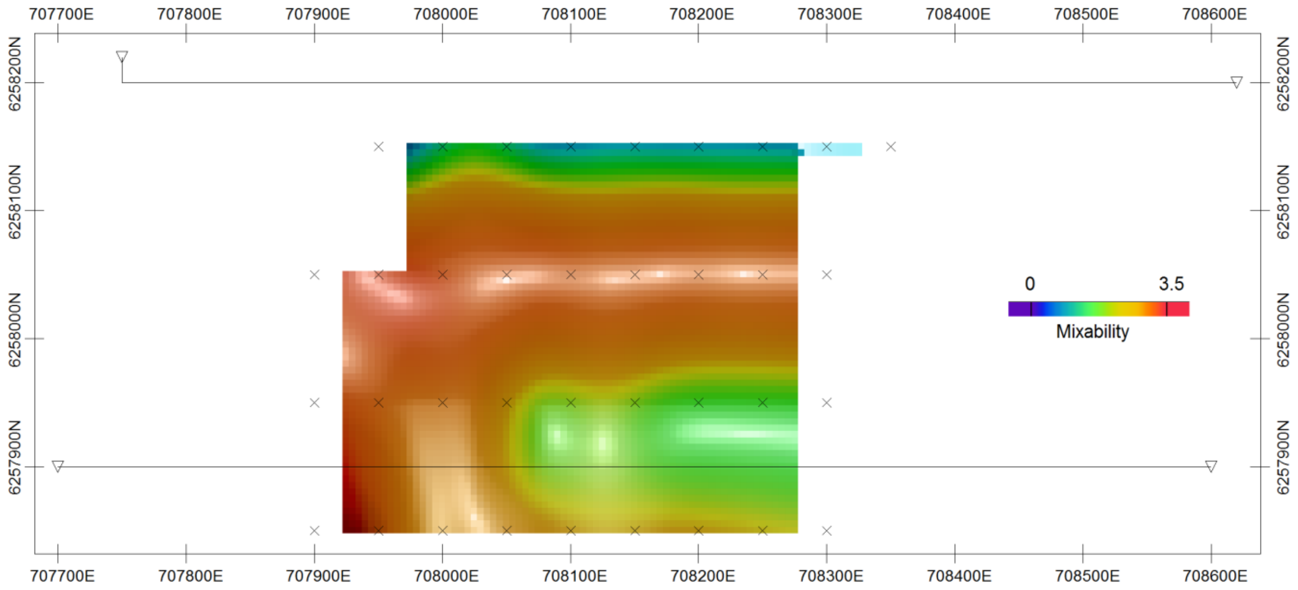

Figure 3 Raw mixability data obtained for the sum (f1+f2) frequency using a 24-bit receiver

Clearly, there are significant problems in the data with variations from line to line swamping the along line fluctuations. The equipment configuration was carefully checked to determine possible causes of the large line to line variation. Faults within the individual ADCs were eliminated as a cause since both ADCs, which are from different manufacturers, behaved in an identical fashion. The only common piece of equipment in the 24-bit and 31-bit configurations was the pre-amplifier. The pre-amplifier was consequently checked in the laboratory with identical primary signals to those measured in the field and no mixing terms were seen in the spectrum, suggesting that the pre-amplifier was not faulty. Local resistivity variations were carefully examined to ensure that it was not the primary normalisation that was causing the observed effects. It was noted that the line to line variation in mixability may have been dependent on the distance from the transmitter wires with those readings closest to these wires having the lowest background values.

Electromagnetic (EM) coupling effects have been examined as a possible cause of the observed background variations, since this will vary systematically with the distance from the transmitter wires. Figure 4. shows a typical waveform at the receiver during this survey. There are transients at the switching times for both primary transmitters due to EM coupling between the transmitter and receiver wires. If the line to line variations are coming from the receiver instrumentation then it is likely to be coming from the pre-amplifier, which was the only common part of the electronics between the 24-bit to 31-bit ADC changeover. The influence of the EM coupling transients from the use of square wave transmitters on the pre-amplifiers was investigated as a possible source of the errors. The pre-amplifier was tested in the laboratory with identical primary signals and no mixing terms were seen. The power supply voltages to the pre-amplifier were high enough (±15V) that the transients should not have been a problem. At this stage, the source of the line to line errors has not been resolved. In future, alternate pre-amplifiers will be trialled and changes made to the primary waveform to eliminate the transients, probably by the use of simple sine waves.

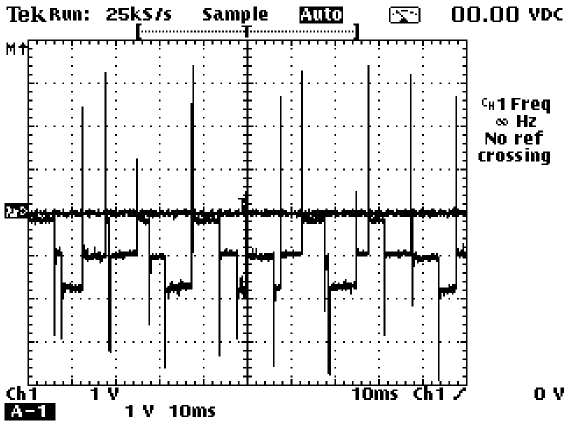

Figure 4 Typical primary waveform from first field trial

Examination of the raw mixability data (Figure 3.) suggests that the line to line error is reasonably consistent for each line. The data also suggest that a strong residual mixability high exists on the western edge of the survey area and the eastern ends of the survey lines were reasonably consistent along line. To examine the residual (without line to line variation) variations in mixability, the value of the second easternmost reading from each line was subtracted from the data for that line to partially remove the line to line error. Figure 5 shows the residual data when the approximate background is removed. This is a crude method of correction, but some interesting data resulted. A strong response exists in the southwest corner of the surveyed area. The main area of interest, in the centre of the survey area has a weak response but considering the crude processing of the data this may be noise.

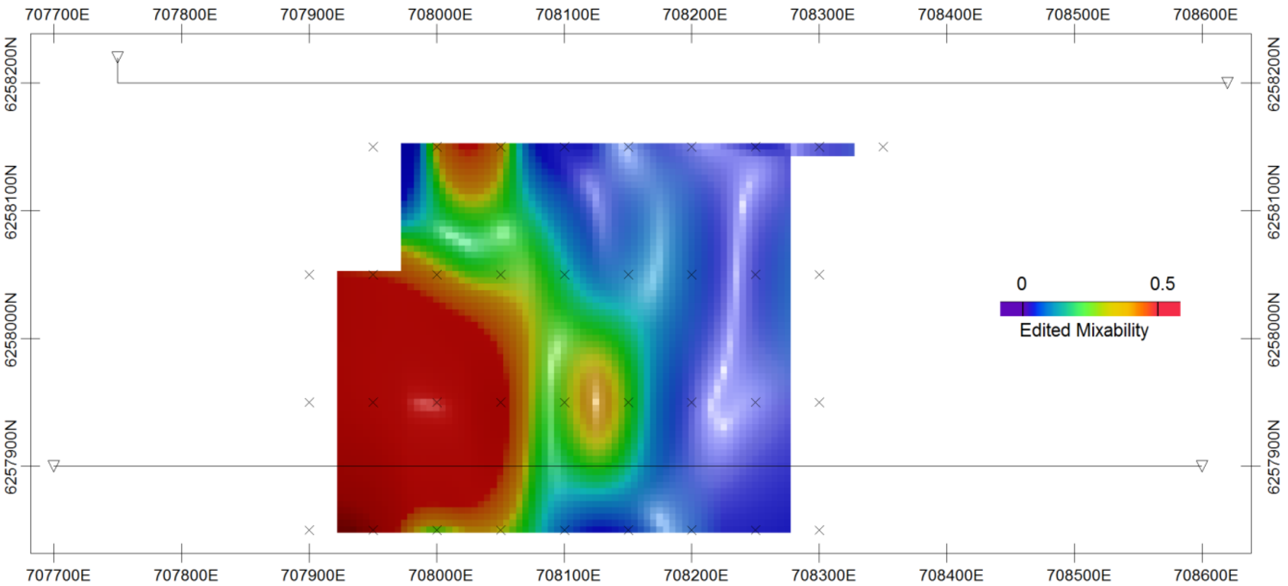

Figure 5. Mixability data after partial correction for line to line errors.

Figure 6. shows a slice through a 3D IP model over the same area at 50m below the surface. There is a broad correlation between the IP chargeability and the SH mixability maps which suggests that the residual variations in the mixability are related to the occurrence of sulphide minerals or that the observed signals are coming from electrochemical (IP) non-linearity. Recent remapping of the geology in the area of the high mixability and a 10 metre drill intersection of gold/pyrite mineralisation (Busch, 2017) suggest that this may be a feeder zone to the VMS base metal mineralisation further east. However, only subtle mixability responses were obtained in the SH data in the area of known poly-metallic sulphide mineralisation in the centre of the survey area.

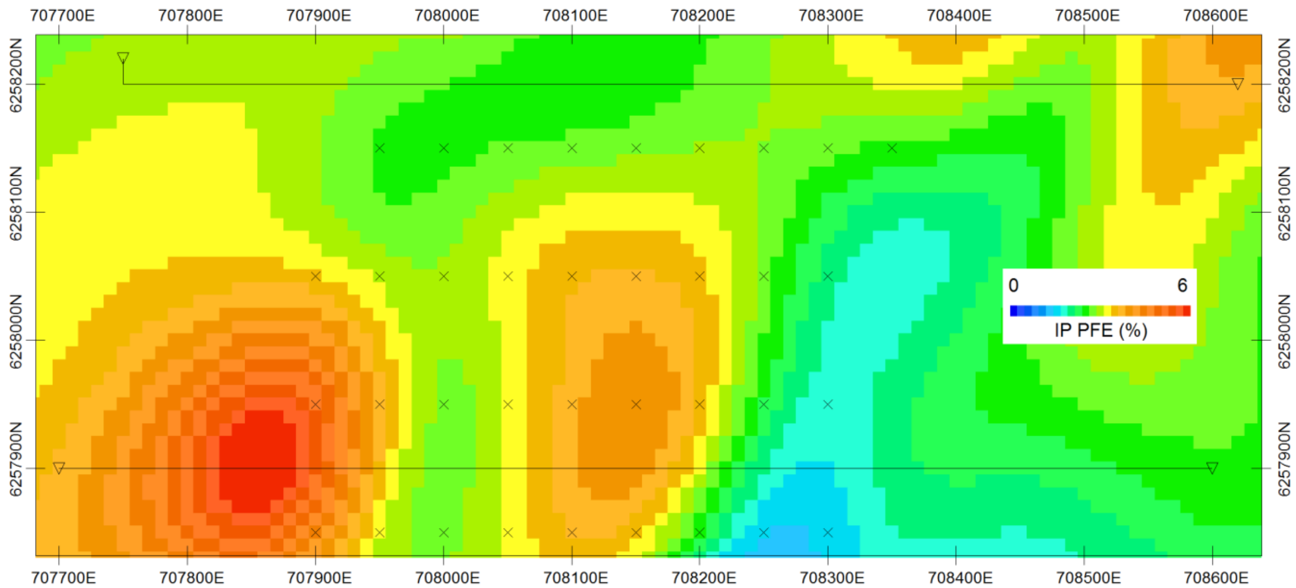

Figure 6 Plan slice through a 3D IP model at a depth of 50 metres below the surface

CONCLUSION

Field tests of the Simple Heterodyne and Biassed Heterodyne methods of exploration were carried out at the Kempfield poly-metallic sulphide deposit. Considerable difficulties were encountered with instrumentation and systemic faults. However, after crude correction for noise and artefacts in the resulting data, the authors believe that the system has detected a response that is related to mineralisation. The nature of the relationship between data and mineralisation is unclear. Further modification to survey equipment and field testing at this and other test sites is planned for the near future. These modifications will include testing using sine wave primary signals, the addition of DC bias circuitry and investigations of the secondary signals with varying primary signal frequencies.

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