Heterodyne Method of Sulphide Detection. Latest field results

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SUMMARY

The Heterodyne Method uses the semiconducting properties of sulphide minerals to produce secondary signals that may be used to map occurrences of those minerals and possibly distinguish between different types of sulphides and graphite.

Several field trials of this technique have been run over the Kempfield prospect in eastern NSW. Many of these trials were plagued by logistic and technical difficulties but a considerable amount of valuable data and experience has been obtained.

The results indicate show that this technique produces mappable results. However, the response to sulphide minerals has only been sporadic and it is clear that the secondary signals produced by this method are extremely complex. Further work is needed to resolve technical issues and ascertain the geological relevance of the large amount of information contained in the heterodyne signals.

Key words: Heterodyne, Kempfield, mixability, non-linear, sulphide.

INTRODUCTION

The Heterodyne Method utilises the semiconducting properties of sulphide minerals (Shuey, 1975) to create an electrical or electromagnetic (EM) signal that can be mapped to locate accumulations of these minerals.

As it relies on an entirely different property of sulphide minerals to other geophysical methods, it has the potential to be able to discriminate between different conducting minerals. In particular, it may be possible to distinguish between sulphidic rocks and graphitic rocks. This is a problem which is very difficult using standard geophysical methods. With future development, the heterodyne method may be able to distinguish different sulphide species.

The exploration technique by which the semi-conducting nature of sulphides is investigated is known as heterodyning, which is a well known technique in electrical and electronic engineering. This method was proposed by White (1974). Electrical (or EM) signals at two or more frequencies are injected or induced into the ground and the distortion of the resultant, which is caused by non-linear conduction in the ground, is mapped. In this study two sinusoidal signals (referred to here as f1 and f2) are input galvanically and, in areas of non-linear conduction, the resultant signal contains not only the original frequencies but also many 'heterodyne' or 'mixing' frequencies. These mixing frequencies are created by the non-linear relationship between current density and potential difference across semi-conducting sulphide grain boundaries. The main secondary frequencies of interest occur at the 'difference' frequency (f2 - f1) and the 'sum' frequency (f2 + f1). The primary frequencies can be chosen such that the mixing frequencies are well away from the primaries and their harmonics and away from expected noise frequencies such as power line noise. minimising problems of noise.

This study only looks at these effects with electrically generated primary signals and only in the frequency domain (2 primary frequencies). Work on electromagnetic induction of the effect and airborne implementation in the time domain has been undertaken by Macnae and Kratzer (2023).

Work on the technique at laboratory scale has been carried out at CSIRO by Oertel et al. (2018) and Oertel (2019). These studies confirm that sulphide bearing rocks respond with secondary mixing frequencies while those without sulphides do not. However, current densities used in laboratory work to date have typically been two orders of magnitude above what would be experienced in the field. This work is continuing, in order to study the effects at lower current densities and for a wider variety of samples. The development of a field implementation of the technique has been described by Collins (2022) and some early results from field testing by White et al. (2018).

The aim of the ongoing field work is to confirm that secondary mixing frequencies can be detected and that these can be used to distinguish between areas of known sulphide accumulations and graphitic shale units.

FIELD TRIALS OF THE METHOD

The Kempfield test site

Seven test surveys using the Heterodyne Method have been conducted at the Kempfield site in eastern NSW. Kempfield is a currently sub-economic volcanogenic sulphide (VHMS) deposit. Most of the mineralisation consists of silver minerals in a barite gangue but there are known lenses of more massive poly-metallic sulphides. There are hundreds of exploration drill holes on the project resulting in very good geological control in the areas of known mineralisation. There are, however, some areas where the drilling data are incomplete or non-existent, particularly in areas of what are considered less prospective lithologies.

Figure 1 shows the geology on the part of this project that has been used to test the heterodyne system. The geology surrounding the sulphide lenses consists of felsic volcanic and volcanoclastic rocks of Silurian Age. These are stratigraphically overlain in the east by conformable sedimentary rocks and in the west are thrust against older Ordovician sediments which contain graphitic shale units. Further west again is late Silurian granite. Strata strike at approximately 35 degrees east of true north and dip steeply to the west. The geology of the prospect has been well documented by Timms and by McGilvray.

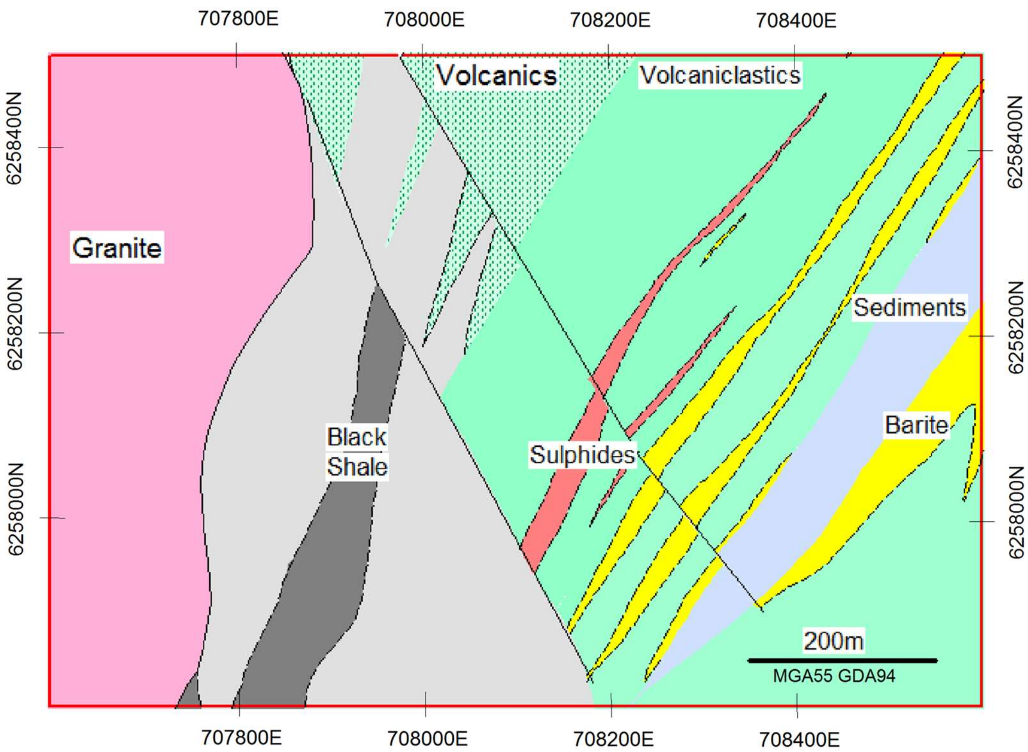

Figure 1. Geology of the Kempfield test site

The geology that is significant to the testing of the heterodyne system is shown in Figure 2. Most of the country rock is moderately resistive (200 - 1000 ohm-m) and is electrically reasonably uniform. Sulphide and graphitic zones are the only lithologies that are relevant to these tests.

Survey method

The survey layout is similar to that used in gradient array Induced Polarisation (IP) surveys. A major difference is that two transmitter dipoles are used, one for each of the transmitted primary frequencies. Figure 2 shows the layout of the test surveys that have been run at Kempfield.

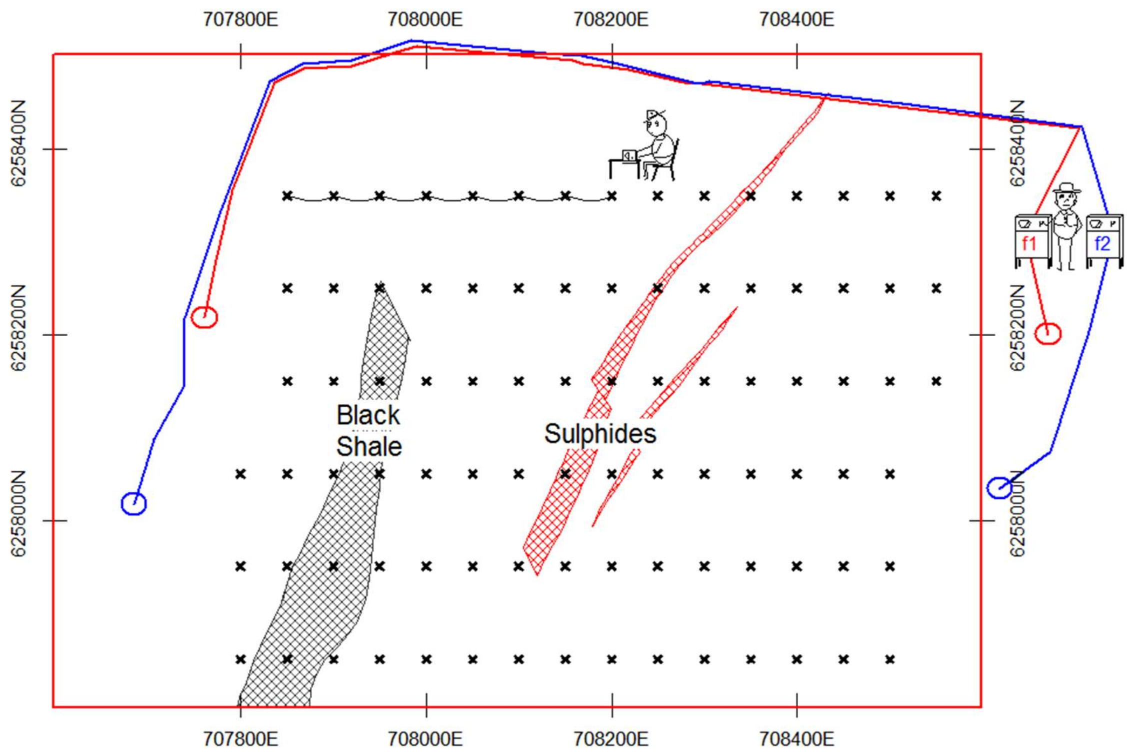

Figure 2. Layout of Heterodyne Surveys at Kempfield

Transmitter dipoles for each of the primary frequencies are separated to ensure that there is no secondary signal emanating from the volume immediately surrounding the ground contact electrodes, where the current densities are relatively very high. There is a separation of 200 metres between the two transmitter dipoles to avoid the signals combining at the contact electrodes. Measurements taken during the test work indicate that the signal at each transmitter dipole from the other one is about 10 percent of the signal being generated by that transmitter. A 10% signal from the other transmitter is sufficient to affect any electronic components in the output stages of the transmitters. For this reason, the transmitters are designed with no non-linear electronic components in their output stages to avoid the generation of spurious mixing signals within the transmitters themselves.

The primary frequencies used have varied from survey to survey as practical lessons were learned. For most of the test surveys frequencies between about 50 and 70 Hz have been used. One of the test surveys used primary frequencies in the 400 to 500Hz range and there were indications that the results were similar but other technical and logistics problems prevented further analysis of these data. Later surveys have tended to use 55 and 68Hz or 60 and 68Hz to minimise the overlapping of higher order mixing frequencies with the first order sum and difference frequencies.

The resulting combined (and possibly mixed) signal is measured using a standard 50m electrical dipole within the area of the survey like gradient array IP. Typical sampling times in the latest surveys have been around 15 seconds but this has been variable.

Data processing

Primary and secondary signals have been captured at 8192 samples per second. The resulting data are sub-divided into groups of 16384 (2 seconds) with a 50% overlap with adjacent groups. These are modified using a Hann window and passed through an FFT routine to give spectra of the sub-groups. These spectra are then averaged to give the Fourier spectrum of the whole sample. Statistics of differences between the sub-groups are used to estimate the noise within each full sample as a means of quality control.

Once the spectrum for each sample is generated, the amplitude at the two primary frequencies is determined, together with the amplitude at the sum and difference frequencies. The sum and difference amplitudes are summed and then normalised (divided) by the sum of the amplitudes of the primary signals. The resultant is multiplied by 1000 to bring it into a reasonable range and this value is plotted to indicate the possible presence of mixing (and by inference sulphide minerals). The resultant value is called 'Mixability' and is in units of millivolts per volt (or permil).

Test survey results

There have been seven test surveys using the Heterodyne Method at the Kempfield site. The object of these surveys has been to confirm that heterodyne mixing signals are produced in the ground, to demonstrate that these signals occur in areas of sulphide mineralisation and to determine whether areas of graphitic shale produce these signals. The surveys have been plagued with logistic and technical difficulties. While valuable lessons have been learnt on each occasion, several of the surveys did not produce any conclusive results.

Following are results that we consider to be significant.

First field test May 2017
This survey used modified IP transmitters generating (noisy) square wave signals at 53 and 80Hz. Only one receiver line (675)8050N [MGA55 GDA94] was successfully recorded (Figure 3).

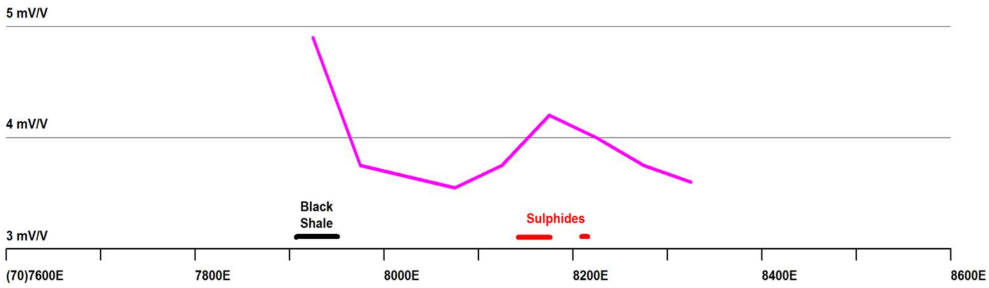

Figure 3. Mixability profile on line 8050N (May 2017)

Results show a broad mixability high over the area of known sulphide mineralisation. However, a strong mixability response at the western end of the line may be due to graphitic rocks. A closer evaluation of the source of the western response suggested that it may be due to mixing signals originating from the transmitter itself. Transmitter wires crossed receiver line 7875E and subsequent testing showed both transmitters were producing spurious mixing frequencies due to mutual interference.

Second to fourth field tests [August 2017, February 2018 and November 2020]
Attempts were made to use transmitter systems that were not affected by the cross coupling, but no results of exploration significance were obtained. Transmitter systems were built with output stages consisting of an alternator and transformer only. Frequency control is achieved by controlling the speed of the alternator. Initially, the alternator speed was controlled mechanically and in later systems the speed was controlled using a feedback system to a driving electric motor (ie a rotary converter). Variable results were obtained but none of exploration significance.

Fifth field test March 2022
A gradient array IP survey was conducted using the same wires and electrodes as the heterodyne survey to get a direct comparison between the two methods. Both transmitter dipoles were used independently and IP chargeability and resistivity from the two transmitters were averaged to get as close a comparison to the heterodyne mixability survey as possible. IP chargeability results for this survey are shown in Figure 4.

The IP survey indicates that the known sulphide zone is weakly IP responsive (<20 mV/V). There is a parallel IP zone approximately 200m to the southeast which is well drilled but has significantly less sulphide minerals. The Ordovician sediments to the west (graphitic shale?) is moderately to strongly IP responsive (+40 mV/V). In the north of the survey area is a moderate IP response (~30 mV/V) in an area of poor drilling control which is of unknown origin.

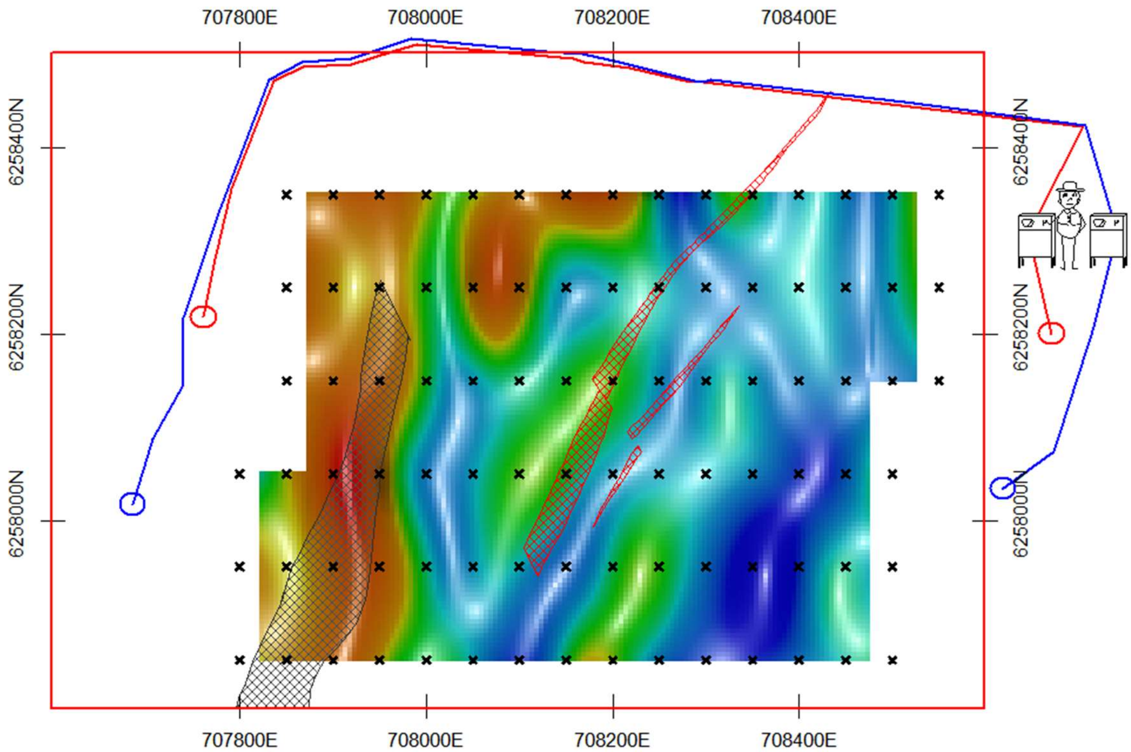

Figure 4. Gradient array IP Chargeability

The heterodyne survey used primary frequencies of 48 and 72 Hz. It was subsequently found that these frequencies, being in the ratio 2:3, were not optimum as the higher order mixing terms (e.g., 2f1-f2 or 2f2-f1) overlapped the sum and difference mixing frequencies. Surveys following this have operated with frequencies which are chosen to separate the mixing terms up to the fourth or fifth order as the results indicate that these are significant.

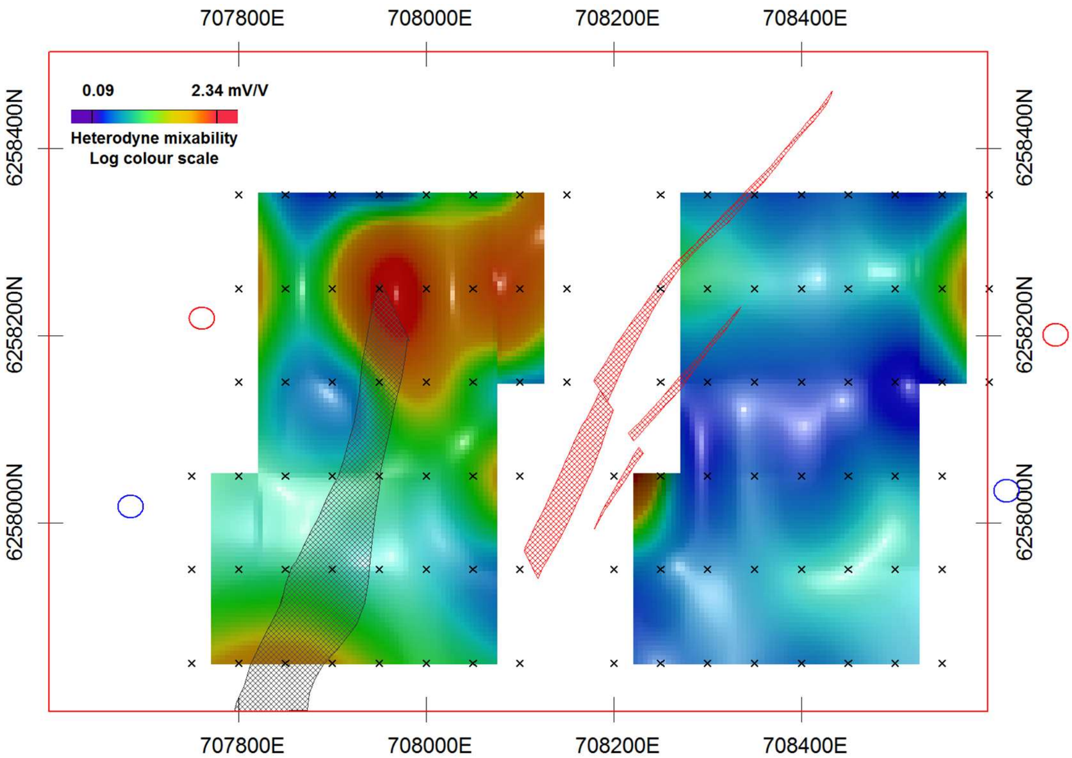

Figure 5. Heterodyne mixability

Despite the sub-optimal choice of frequencies, reasonable mixability values were obtained despite these being distorted by the higher order terms. Unfortunately, a wiring problem with the receiver resulted in a major gap in the coverage. This gap occurs over the main area of interest where sulphides are known to occur. However, some crucial information can be obtained from these data.

There appears to be rising mixability values towards the central zone of known sulphides, suggesting that this is an area of elevated heterodyne mixability. This is consistent with the original heterodyne field survey which shows a broad response in this area. It is also consistent with the gradient array IP data having a moderate response here.

In the west, there is no significant response over the area of black shale, despite this area having a strong IP response.

In the northwestern quadrant of the heterodyne survey there is a strong mixability high which is partly coincident with an IP response. The cause of this response is unknown but its coincidence with an IP response suggests it is at least partly associated with sulphide minerals. There is no drilling information in this immediate area.

Minor mixability highs at the western and eastern edges of the survey are believed to be due to the proximity of these readings to the transmitter electrodes. A mixability high on the western half of the southernmost line is probably associated with a grounded mesh fence.

Sixth field test September 2022.
Heavy rain at the time of this survey caused logistics problems and resulted in dubious readings from the receiver system and a short circuit in one of the transmitters. The faulty transmitter was replaced with a simple 50Hz source but as a consequence one of the transmitters had poor frequency control. No useable data resulted from this survey.

Seventh field test November 2022.
Weather again prevented the full scheduled survey. However, three lines were surveyed using the same receiver system as previous tests. All six test lines were able to be surveyed using the AGT gDAS32 distributed data acquisition system.

The mixability calculated for the initial survey shown in Figure 6. Frequencies used are 48 and 72Hz to match the fifth field test.

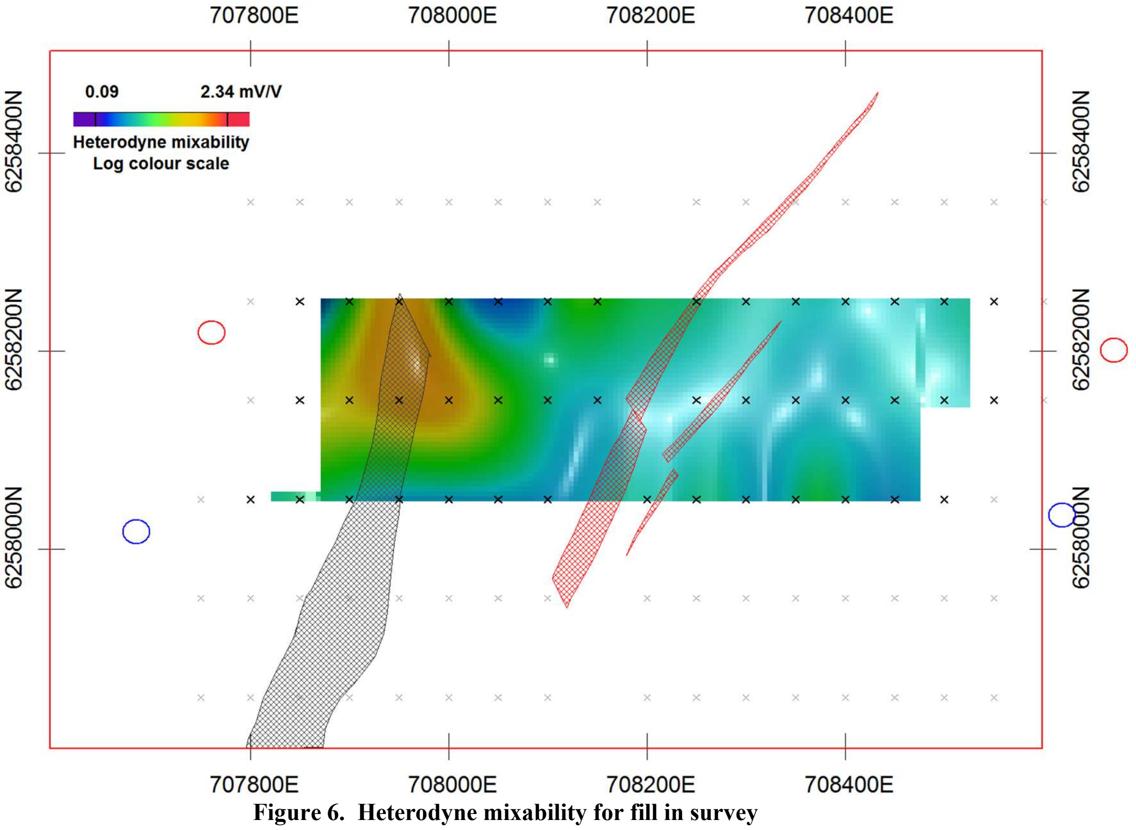

Figure 6. Heterodyne mixability for fill in survey

The seventh field test failed to confirm a response over the area of known sulphides. There are several possible reasons for this, such as that the sulphide zone may not be sufficiently massive to generate a heterodyne response, or the currents used may be insufficient.

Results collected with the gDAS32 system also failed to detect the sulphide zone. Figure 7 shows gDAS32 mixability results for the 55 Hz : 68 Hz frequency combination.

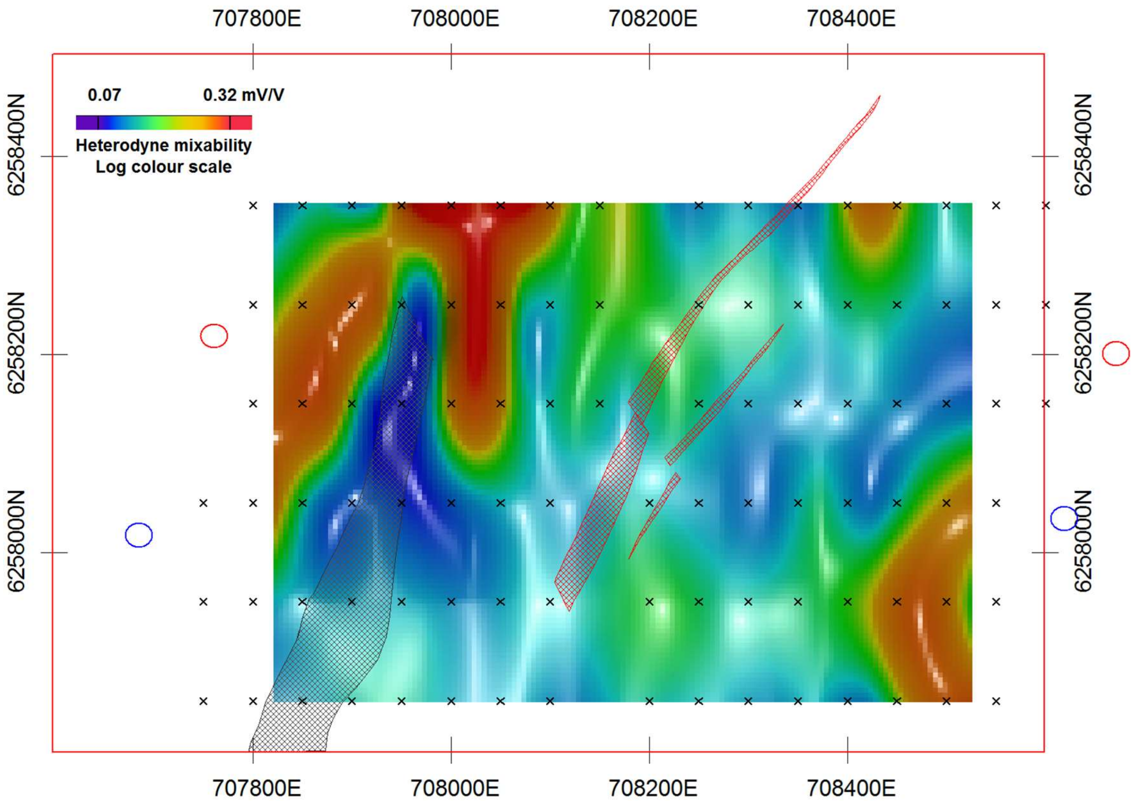

Figure 7. Heterodyne mixability from gDAS32 receivers (55 and 68Hz)

Theoretically the gDAS32 results should be identical. However, the earlier results are complicated by the fact that the frequencies used, 48 Hz and 72 Hz, are in a simple ratio of 2:3 which results in higher order mixing terms overlapping with the sum and difference frequencies, from which the mixability factor is calculated.

Analysis of the spectra of the results reveals an interesting fact. The higher order mixing terms (intermodulation products) are in many cases significantly stronger than the sum or differences frequencies. Figure 8 shows the amplitude spectrum for a 55 Hz : 68 Hz transmitter frequency pair recorded at 707975E / 6258150N. The amplitude at frequencies 2*f1-f2 and f1+2*f1, and others are significantly stronger than the sum and difference frequencies. In some cases the higher order terms are an order of magnitude greater than the sum and difference values. When the primary frequencies are in a simple ratio such as happens at 48 :72 Hz, the higher order mixing terms will be superimposed on the sum and difference and will radically change any estimation of the mixability factor. Thus, it is important to choose the primary frequencies carefully so a true estimation of the mixability is obtained.

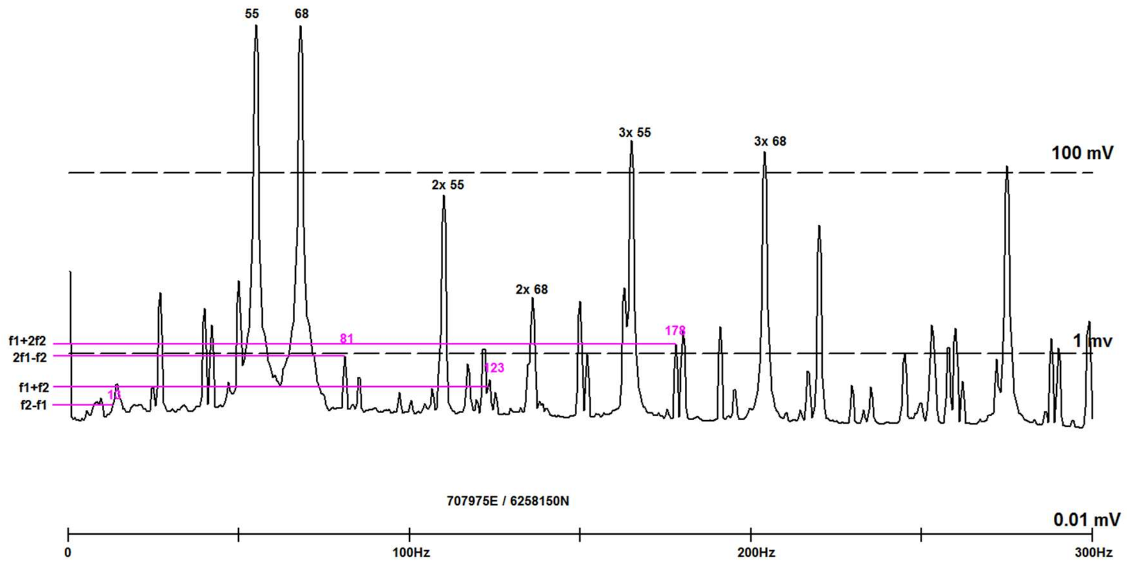

Figure 8. Log amplitude spectrum for 55 :68 Hz at 707975E / 6258150N.

CONCLUSIONS

Field testing of the Heterodyne method for sulphide exploration and mapping has shown that there is not a simple relationship between the existence of subsurface sulphide minerals. However, the method does appear to be mapping some factors that are related to the geology of the surveyed area. The complex signatures that have been obtained in these tests contain a wealth of geological information that may include information about minerals occurrences which is relevant to the exploration for sulphide minerals.

Future testing of the method will need to use carefully chosen primary frequencies and analysis of the higher order mixing terms may provide valuable information about the subsurface geology and mineralisation.

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