Heterodyne Method for Sulphide Mapping. Latest field data

Steve Collins
Retired
scollins@arctan.com.au

Keith Leslie
CSIRO
Keith.Leslie@csiro.com

Andrew Sloot
Fender Geophysics
andrew.sloot@fendergeophysics.com.au

SUMMARY

The Heterodyne Method attempts to use the non-linear electrical properties of certain minerals (specifically sulphide minerals) to map these in the subsurface. The method attempts to generate heterodyne frequencies detectable at the surface over known sulphide occurrences. Several field tests of this method have been undertaken over many years. This paper summarises the latest results obtained and difficulties faced in developing a practical field survey technique for this method.

A field test of the technique was carried out at the Mallee Bull sulphide deposit near Mt. Hope NSW in August 2023. The Mallee Bull deposit is a steeply dipping massive sulphide lens which is strongly conducting and was discovered using heliborne electromagnetic techniques. East of the deposit is a broad zone of disseminated pyrite and pyrrhotite that is relatively close to the surface. This zone is IP responsive and conducting in parts.

The heterodyne survey was designed to cover both the deposit and the zone of disseminated sulphides. For reference a gradient array IP survey was run at the same time using the same electrodes. Complex technical and logistical difficulties arose in the conduct of this survey.

The technique produced clear heterodyne signals showing that non-linear conduction is occurring as was found in previous field surveys. However, finding the source of these signals remains problematic. Technical problems during the survey has meant that only one survey line of data can be shown to be completely valid. The data analysis revealed what appears to be a clear correlation between anomalous heterodyne signals and known sulphide occurrences, particularly the area of disseminated sulphides. The survey has highlighted that the recorded data contains significantly more information than was previously considered and work is ongoing to unravel this complicated data and determine its exact geological significance.

Valuable insights into the possible uses of this technique have been gathered in this field test and many unforeseen logistical problems have been resolved. Unfortunately, the question of the practicality of the Heterodyne method has not yet been fully resolved.

Key words: Sulphide exploration, Heterodyne method, Mallee Bull deposit

INTRODUCTION

The Heterodyne Method attempts to map the distribution of non-linear electrical conduction in the subsurface. The goal of this process is to distinguish mineral types, specifically to distinguish sulphides from graphite, which often occurs in prospective strata. The method relies on the heterodyne process whereby two frequencies of alternating current are mixed together in a non-linear medium but remain separate in areas of linear conduction. It is hoped that the character of the mixing can be determined as a guide to the types of minerals present. The method has been explained in detail by White et al.(2023), and by Collins et al. (2022). The method was originally proposed by White (1976).

The aim of this research is to determine if a practical field method can be developed to map the heterodyne effects and hence non-linearity in the subsurface. Numerous field surveys have been conducted over the period 2017 to 2023 and more are in the planning stage at the time of writing. All surveys to date have used a modified gradient array geometry as described in previous papers. This abstract covers the problems arising during the conduct or a test survey at the Mallee Bull massive sulphide deposit in August 2023.

CONSTRAINTS ON THE SURVEY OPERATION

A gradient array geometry is used. Each of the primary transmitted signals is injected into the ground using independent transmitters and electrodes. This array geometry is used to avoid the two transmitted signals interacting in the area of extremely high current density immediately surrounding the transmitter electrodes. The two pairs of transmitter electrodes are kept a minimum of 200 metres apart. At this distance the potential from the other frequency is less than 1% of the potential on the electrode. It was hoped that this will be low enough to avoid mixing of the signals at the transmitter electrodes. Despite this precaution, some evidence of heterodyne signals being generated at the transmitter electrodes has been seen in receivers which monitored the transmitted currents.

To reduce the chance of mixing occurring within the transmitters themselves, the use of electronic components in the output circuit of the transmitters is near zero. This is achieved by using a mechanical connection such that the output circuit consists only of a permanent magnet alternator, a transformer, the electrodes and the ground. Thus there are no non-linear components in the transmitter equipment. However, the possibility of non-linearity in the electrode ground interface cannot be eliminated. Frequency and phase control of the output is achieved by adjustment of the speed of the alternator.

It is important to have highly linear receivers. In order to check that receiver non-linearity is not a problem, two separate receiver types have been used in the latest test. The first is a purposely built system (KL receiver) as has been used in previous field trials. The second is a commercially available distributed data acquisition system, Southernrock's gDAS-32 (gDAS receiver). Unfortunately, technical and logistical issues arose with the gDAS systems and to date the validity of data from these have not been fully verified. The gDAS data are not discussed here.

The possibility of non-linearity at the receiver electrodes also remains. Receiver electrodes consisted of stainless steel stakes but the linearity of these has not yet been investigated.

In order to check for the possibility of spurious heterodyne signals originating from the transmitters, two gDAS receivers have been used at the transmitters to monitor exactly what is coming from each transmitter system. These monitors use a Hall effect sensor surrounding but not connected to the transmitter wires to accurately measure the current in those wires without the possibility of imposing non-linear components. This monitoring system appears to have worked well and the data is helpful in determining the origin of the observed heterodyne signals.

THE HETERODYNE SURVEY

The test survey was conducted over the Mallee Bull polymetalic massive sulphide deposit and nearby pyritic / pyrrhotitic stringer system. The Mallee Bull deposit occurs near the township of Mt. Hope in central N.S.W. It lies within the metal rich Cobar Basin. A description of the geology is given by Brown et al. (2015). A geological cross section is provided at Newexco (2024). It consists of massive sulphide lenses which strike south-north and dip moderately to the west. The base of oxidation is at approximately 100m depth. The centre of the bulk of the deposit at depth lies at about 415225E / 6,413,400N (MGA Zone 55 coordinates). The top of the deposit rolls to the east so is further east at about 415,350E. The near surface zones are lead/zinc rich and the bulk of the deposit is copper rich at depth. The deposit was discovered following a VTEM helicopter electromagnetic (EM) survey in early 2011. The copper portion of the deposit is a strong EM conductor but the deposit only responds weakly to Induced Polarisation (IP) mostly from the near surface lead/zinc zone. Approximately 300 metres east of the deposit is a broad zone of disseminated pyrite / pyrrhotite at a significantly shallower depth (less than 50 metres). This zone responds moderately to IP and is conducting in bulk at depth.

The heterodyne survey was designed to cover the area over both the massive sulphide lenses and the disseminated sulphide zone. A survey area of 1km square was selected in the hope that this could become a standard geometry for future surveys. However, the current density for this test is suspected to be too low and the size of future test surveys will be reduced. The transmitter electrodes were placed 2km apart and the two transmitter electrode pairs are separated by 200m from each other. Receiver lines are 100 metres apart with readings every 50m using 50m dipoles. Gradient array Induced Polarisation (IP) was also measured over the same area using the same electrodes.

The geometry for these surveys relative to the sulphides is shown in Figure 1 with the gradient array chargeability results. The gradient array resistivity results are shown in Figure 2. The deposit is not visible in the gradient array IP data. There is a distinct resistivity low over the top of the deposit, probably due to weathered sulphides. The heterodyne survey was run over the same area as the IP with the gDAS receivers but due to technical issues the data are not available at this time. A single line of heterodyne data was obtained on line 6,413,300N using a purpose built (KL) receiver. It is data from this line that is discussed here.

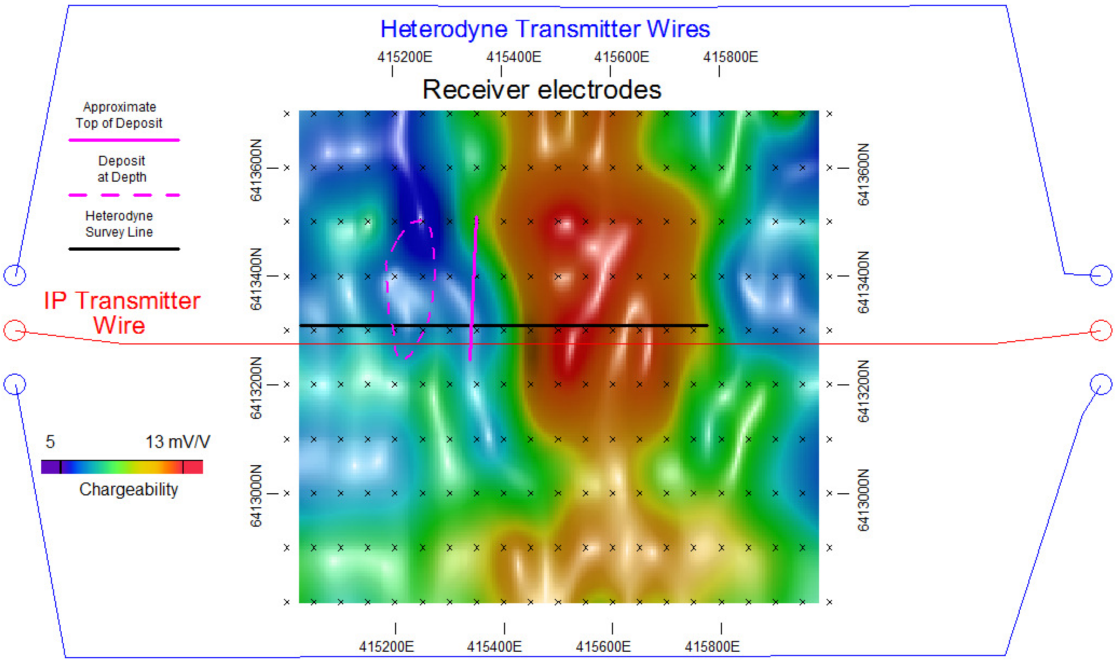

Figure 1 Mallee Bull Gradient Array IP Chargeability and Heterodyne Survey Layout

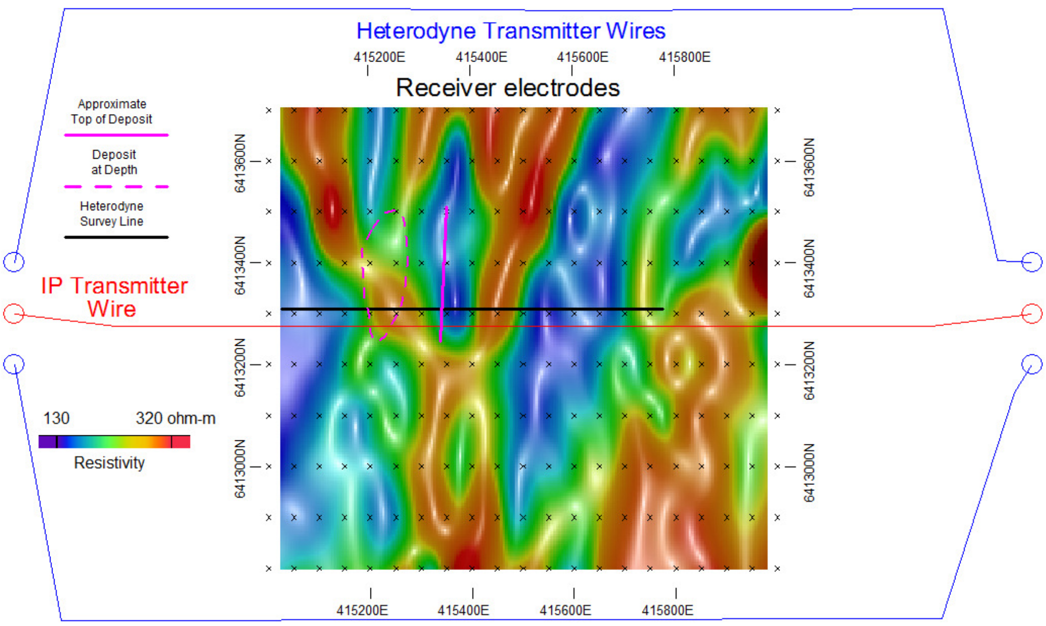

Figure 2 Mallee Bull Gradient Array Resistivity and Heterodyne Survey Layout

PROCESSING THE DATA

The heterodyne process creates large amounts of data. A mixing (heterodyne) signal contains the two original frequencies plus a multitude of secondary frequencies. These secondary signals are at frequencies which are at multiples of the primary frequencies in the form aF1 +/- bF2 where F1 and F2 are the primary frequencies, and coefficients, a and b, are integer values. The term 'order' is used to describe a group of integer coefficients based on the sum of their values. For example a frequency of 3F1-2F2 would be 'of order' 5.

Early attempts to measure these signals combined the second order terms into a single value referred to as Mixability, which normalises the secondary by the primary signals to remove any affect of local ground resistivity variation. (White et al., 2018). It was found both theoretically (Lankford, 1993) and in practice (Collins et al., 2022) that this simple approach was inadequate to describe the field results. This was expanded to measure response at higher orders, such that the average of the signal amplitudes of all frequencies of a particular order were normalised. (White et al., 2023)

Results from the Mallee Bull survey suggest that individual heterodyne frequencies can behave differently from each other, even within the same order. It has been found that the mixing frequencies with the largest variation between the integer coefficients are stronger than those where the frequencies are closer. For example, in order 5, the amplitudes of 4F1 +/- F2 and 4F2 +/- F1 are stronger than those where the coefficients are 2 and 3. Also, the frequencies where the coefficients are additive mostly tend to be stronger than those where they are subtractive. Signals of odd orders are generally much stronger than those of even orders. The extent to which these generalisations apply will depend on the exact nature of the non-linearity and hence the non-linear electrical properties (mineralisation) of the target.

Figure 3 is a profile of fifth order mixabilities on line 413,300N.

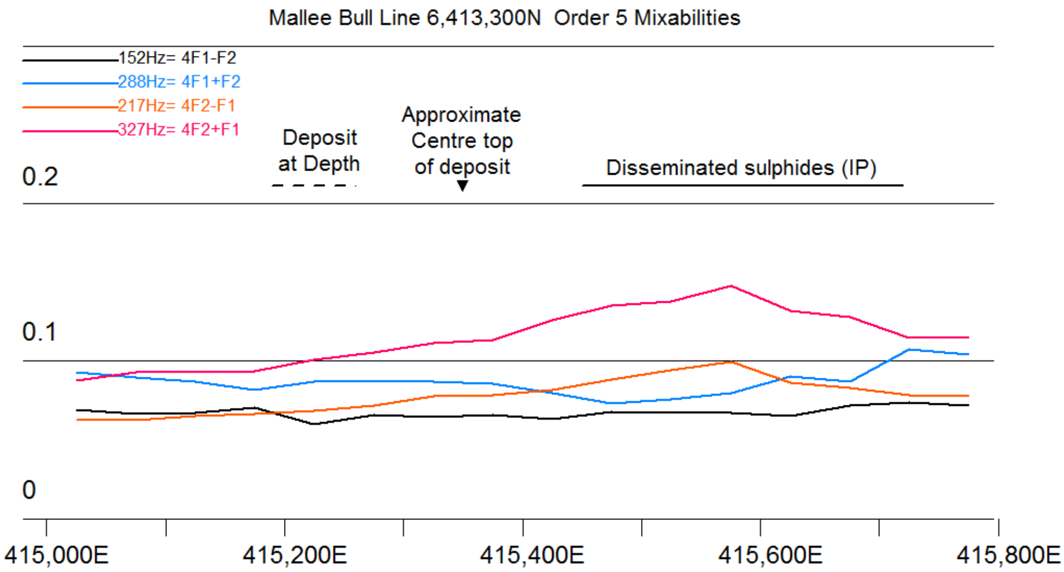

Figure 3 Mallee Bull Heterodyne Mixabilities of Order 5

Profiles of order 3 and order 7 are similar to those of order 5. The strongest response occurs at order 5. Profiles for even-order frequencies are flat, with no response over either the main ore deposit or the disseminated zone. This is consistent with theory and with previous field experience.

There is no mixing response over the main ore deposit at Mallee Bull. However, the main part of the deposit is relatively deep, at over 100 metres. At this depth the current density may be insufficient to cause a significant mixing response. This field test used a transmitter electrode separation of 2 kilometres, reducing the current density in the ground significantly from previous test surveys. The greater depth of the sulphides at the Mallee Bull site will also drop the current density at the target. Future test surveys with this method will adjust the survey geometry to address this problem.

A weak but significant heterodyne response occurs over the zone of disseminated sulphides. It is assumed that this is due to sulphides relatively close to the surface at this location. It is also possible that there is some non-linearity associated with the IP response at this location. This is unlikely but without further field tests it remains a possibility.

CONCLUSIONS

As with previous field tests of this method, heterodyne signals have been clearly observed. However, the relationship of these to known geology is complex. No anomalous heterodyne signals were detected directly above the main ore zone at Mallee Bull, possibly due to low current density at the target.

Subtle but clear heterodyne responses were detected over a zone of near surface disseminated sulphides. It is possible that this is a manifestation of some non-linearity in the IP response from this zone but it is considered, by the authors. more likely that this is a heterodyne signal from sulphide mineral junctions.

Higher order heterodyne signals can be significantly larger than low order signals. Even-ordered heterodyne responses are significantly lower in amplitude than odd-ordered frequencies at the same location.

Some spurious heterodyne signals appear in the transmitter currents. These signals have characteristics that suggest these are generated at the connection of the electrodes to the surrounding ground.

It is probably not technically possible to maintain effective current densities in the earth using large survey arrays. Future tests will utilise smaller survey areas.

ACKNOWLEDGMENTS

This research would not have been possible without the continuing strong support from Fender Geophysics.

The authors thank CSIRO and Southernrock Geophysics for support and Peel Mining for access to the Mallee Bull deposit.

Particular thanks to Mr Bob White who has been a key participant in this research from the outset. Bob unfortunately died from cancer at the same time that this survey was in progress. He was closely involved until the end. RIP Bob.

REFERENCES

Brown, R., et al., 2015, The Anatomy of Mallee Bull: http://www.smedg.org.au/mines-and-wines-2015-files/presentations/BrownEtAl_MalleeBullCobar.pdf

Collins, S., White, R., Leslie, K., & Sloot, A., 2022, A completely different geophysical way to explore for sulphides. Heterodyne method - latest progress and field results, Presentation, ASEG-SMEDG; https//www.youtube.com/watch?v=Df_N-ke91e8&t=836s

Lankford, D., 1993, 2nd, 3rd, 4th, 5th, And Higher Order IMD. : https/www.okdxf.eu/lankford/2nd, 3rd, 4th, 5th, And Higher Order IMD.pdf

Newexco, 2024, Mallee Bull Cobar Style Polymetallic discovery: http://www.newexco.com/discovery/mallee-bull/mallee-bull-cobar-style-polymetallic-discovery/

White, R. M. S. 1976, A Study of Nonlinear Effects in Mineralised Rocks: M.Sc. Thesis, Macquarie University, NSW, Australia.

White, R., Collins, S., Leslie, K., Oertel, A., & Sloot, A., 2018, Field trials of the Biassed Heterodyne Method of Exploration for Sulphide Minerals. ASEG extended abstracts, https://doi.org/10.1071/ASEG2018abM3_2F.

White, R., Collins, S., Leslie, K., & Sloot, A., 2023, Heterodyne method of sulphide detection. Latest field results. AEGC2023 extended abstracts.