Recent SPECTREM^{Plus} AEM Developments

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ABSTRACT

As a result of a major upgrade to the transmitter and aircraft, the SPECTREM Plus system was commissioned at the end of 2015. The update was designed with two main purposes in mind; to improve the signal to noise in order to generate better shallow and deep sounding data as well as improve the geological mapping and target discrimination. The improvement in the 100% duty-cycle waveform proved to be optimal for quantitative interpretation and detection of targets under conductive cover. After collecting data over a variety of areas in Southern Africa, the new system performances has exceeded the design specifications and the focus is now on the upgrade of the receiver bird that is currently taking place and to be implemented shortly.

INTRODUCTION

The last upgrade on the SPECTREM platform was done in 2000 and the system has covered many parts of the world where a number of discoveries have been made. Examining the results of the many 1000's line km of data gave the SPECTREM team a good indication on the best approach to adopt to further improve the system.

In early 2010, Anglo American and De Beers decided to commercialise the system and shortly thereafter a decision was made to upgrade the platform. The initial focus was on the transmitter and loop. This is now being followed up with receiver system development. The design criteria were:

- Increase the resolution of geological mapping,
- Deeper penetration while still able to map shallow features,
- Ability to operate in conductive terrain,
- More efficient discrimination and selection of targets,
- Safe and cost-effective operation.

The airborne electromagnetic method is rapidly becoming a widely used technique for a combination of detailed geological mapping and hydrogeological applications. The days of a bump-detector have long gone as evident in recent publication by Legault, et al (2015).

SPECTREM TRANSMITTER

The system is hardly ever available for major R&D programs and no other platform is available to Spectrem Air for parallel development and testing. It was however decided to continue to develop and test innovative ideas, first on the ground, without taking the current SPECTREM system out of production, and then in flight.

Design:

Based on the SPECTREM patented Resonant Inverter Circuit, originally described by Ferreira et al (2004), the upgrade was conducted using state-of-the-art electronic components and technology. The previous SPECTREM system generated bipolar (100% duty cycle) 960 Amperes RMS. The challenge was to develop a new system with double that current, with a rise time of less than 300 microseconds and capable of operating at frequencies of 25 Hz and lower. The problem was solved by innovative techniques using a number of parallel modules with 1800 to 2000 Amperes is now transmitted in the loop

With the significant increase of current and voltages throughout the various systems, it was also critical to implement a variety of safety controls that monitor a range of various parameters that would lead to an automatic shut down of all the geophysical equipment thereby ensuring the safety of the crew and aircraft.

The replacement (or even an upgrade) of an airborne EM transmitter always contain a significant amount of technical risk. In order to minimise that risk, it was decided that the project would be implemented in a number of discrete phases with well-defined milestones that would need to be proven and tested before the next portion of the project is given the go-ahead.

Development and tests:

The new transmitter modules were extensively tested in the laboratory for more than a year under various operating conditions. A set-up duplicating the aircraft installation is shown in Fig. 1.

A measurement of the combined current is shown in Fig. 2. The desired sharply-defined square wave current is exactly what was required for our particular applications.

Figure 1: Bench testing of the new SPECTREM^{Plus} transmitter

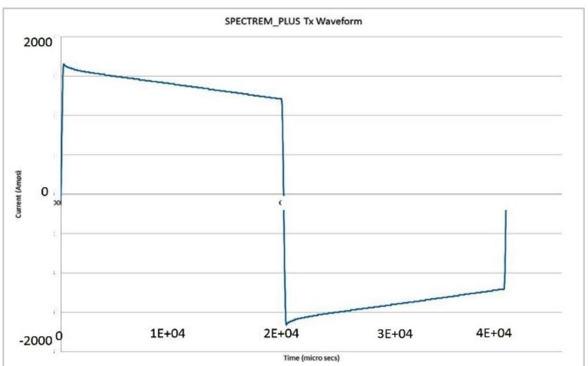

Figure 2: Measured SPECTREM^{Plus} current waveform showing current (A) against time (msec)

The new SPECTREM^{Plus} wave shape has a much sharper edge right after the transition, compared to the previous system, resulting in more early time for better shallow mapping.

TRANSMITTER LOOP

The project was initiated with an analysis of the aerodynamic flow field around various cable configurations that are to be spanned around an aircraft. The simulations are performed using a commercial Computational Fluid Dynamics (CFD) software.

The study consisted of two phases; the aerodynamic characteristics of a single cable configuration followed by a detailed investigation of different configurations of cables and supporting high strength very low stretch braided rope manufactured using Vectran. This resulted in a configuration with the best combination of drag and heat transfer.

Design:

Spectrem Air evaluated the possibility of 1, 2 or 4 cable lengths around the aircraft and taking into considerations all operational practicalities.

A single length of copper cable around the aircraft (only broken in the nose) was selected because it is simpler in terms of electrical characteristics, and the amount of spare cable when operating away from home. However if any defect is detected, the entire (+/- 80m) cable will have to be replaced. A single copper cable has relatively low drag load, good heat transfer properties and allows for added safety to be built into the design (dual redundancy). With 2 synthetic ropes and a single copper cable, the load share is significantly biased towards the synthetic ropes, allowing the copper cable to transfer a smaller portion of the applied loads. This option is also the simplest in terms of aircraft integration.

Due to the transient and variable nature of the air flow around the cable configurations, values for drag and lift needed to be calculated accurately. An example is given in Fig 3.

In general, adding Vectran ropes in front and/or behind the copper cable tends to increase the drag as expected but well within the aircraft performance capabilities. The forces alone are not the only factors to consider, but issues of temperatures and heat transfer coefficients and safety of the installation needed to be properly investigated.

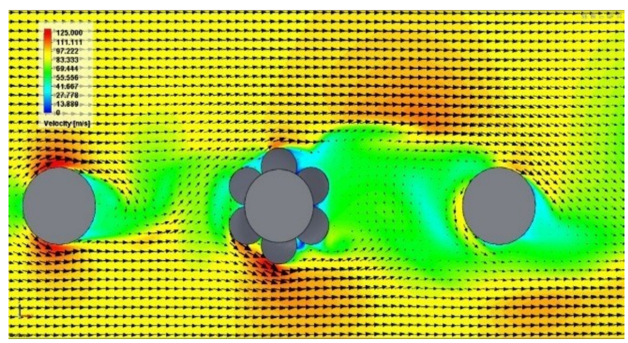

Figure 3: Cable velocity contours and vectors.

With a high electrical current of up to 2000 amperes, the cable will operate at elevated temperatures. This heat is dissipated by means of convection heat transfer due to the free air stream flow. In the temperature calculations, a heat source is applied to the cable as a surface heat source and the cable surface temperatures are then calculated. Even though the maximum temperatures of the cables are in excess of 100˚C when the system is tested at full power on the ground, the average temperatures are below 40˚C during flight. The maximum temperatures are localised as shown in Fig 4.

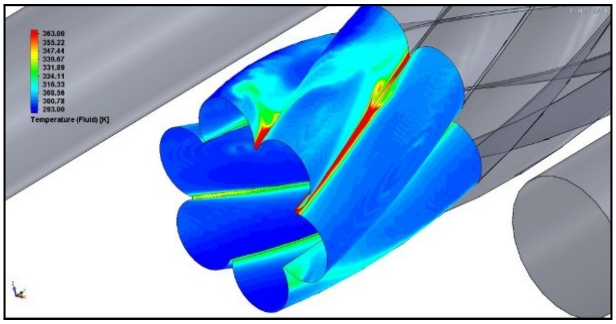

Figure 4: Cable surface temperatures.

Tests:

A number of laboratory bird strike tests were conducted ahead of any installation and modification to the aircraft. The objective of the tests was to determine the tension loads in the copper cable and Vectran ropes during a bird strike scenario. The test was done on cables and ropes at a full scale test setup as shown in Fig 5.

Figure 5: Loop cable and ropes for bird strike tests.

Through the use of an air cannon (right portion on Fig 5), a bird was accelerated to strike the cable / rope setup. The tension in the ropes and copper cable due to the impact load were measured by means of load cells. The velocity of the bird was selected to represent the aircraft's cruising speed.

For each of the bird strike tests conducted, an energy load spike of between 0.002s and 0.004s was seen in the data due to the sudden application of load to the system. This peak load immediately reduces to acceptable levels and the system responds as designed with a very low impulse that would not have a direct effect on the aircraft or loop structure.

From a geophysical perspective, the new loop and transmitter have been a great success. The increased transmitter power has resulted in mapping deeper and more conductive geophysical targets. Additionally the B-field step response data showed increased signal to noise, which is important in areas of increased cultural noise. The new loop came at a cost in that it affected the drag and performance of the aircraft to extent. Some high drag components have been identified and improvements to the aerodynamic aspect of these components is taking place.

SPECTREM RECEIVERS

As with many other fixed-wing airborne service providers, SPECTREM AIR's focus has been on improving the bird aerodynamic, the coil suspension system and acquiring actual 3D position of the receiver sensor.

Receiver bird design:

Even though the current suspension has been producing very good data over the last 10 years, the bird pitch resonant frequency is too close to the coil suspension resonant frequency and this is evident during turbulent survey conditions. Recent tests indicate a reduction in the bird's pitch resonant frequency from the existing 1.5Hz to 0.4Hz which will translate into more acceptable noise values over a range of flying conditions.

Most of the manufacturing is now done in 3D printing where the printed parts are found to be very reliable, cost effective and quick to produce.

The suspension system is devised in two sections. Fig 6 indicates outer suspension damping of 2.1 Hz (translational movement) and the inner suspension damping of 0.51 Hz (rotational movement) of the existing air suspension. Both these suspensions play a vital role in the overall damping of the receiver, which ultimately determines the resonant frequency.

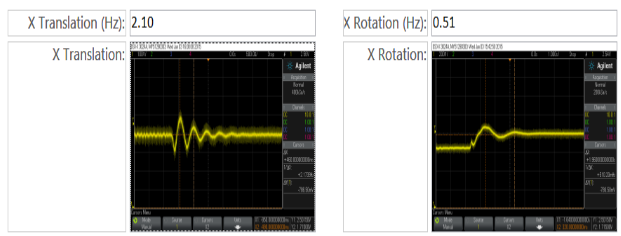

Figure 6: Translational and Rotational damping frequencies

The receiver coil movement in the primary field as well as the precise location of the bird itself are still some of the major unknowns on most of the available AEM systems.

A high specification inertial measurement unit (IMU) has been incorporated in the new suspension design to record the actual movement of the coil. The IMU is also fitted with an external GPS antenna, which will be mounted on the bird's shell. Both the coil movement and bird's position will be used in the processing.

Some measurements would be significantly enhanced by measuring the gradient of the received EM signals or by just increasing the distance between the transmitter and the receiver. Spectrem Air is currently investigating the use of a receiver on a UAV (or array of UAVs) deployed behind the SPECTREM DC3 aircraft. This is something that would only become feasible in the next few years as legislation is put in place.

The development of new sensor technology that would replace conventional coils or current B-field receivers is also very exciting as it will provide better low frequency airborne EM data at 12.5 HZ or 7.25 Hz in the near future. Such a sensor should be available in the next year or two.

In parallel to the development of new towed EM bird, Spectrem Air is also studying a towed magnetometer array that would considerably improve magnetic data resolution. Due to the unique 100% duty cycle waveform, SPECTREM magnetic data is measured from a towed bird rather than a stinger-type configuration as the primary field close to the aircraft overshadows the earth's magnetic field. The aerodynamics of such a bird is crucial in order to record data within acceptable noise levels.

New lighter commercial magnetometer sensors are making it possible to measure data in a much smaller bird and the existing design has been adapted to accommodate a horizontal gradiometer (a nominal separation of 5 m) configuration with an additional sensor in the nose of the bird. Investigations are currently in place to see if a third sensor, can possibly be added in the vertical axes, in order to measure a tri-axial gradient.

AEM RESULTS

Significant improvement in signal to noise ratio were achieved with the new transmitter and loop configuration of the SPECTREM^{Plus} system. An example is presented on the conductivity image in Fig 7 where a unit is now clearly visible with the SPECTREM^{Plus} (bottom panel) compared to the previous system (top panel).

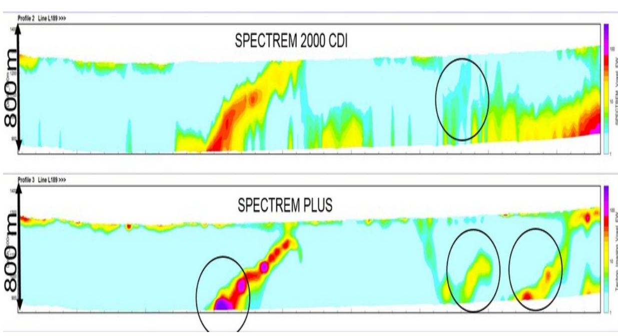

Figure 7: Improvement in depth measurements of SPECTREM^{Plus} data

The mapping of shallow geology is still maintained with the new enhanced power system as shown in Fig 8. In this case shallow and deep basement lithologies are well characterised.

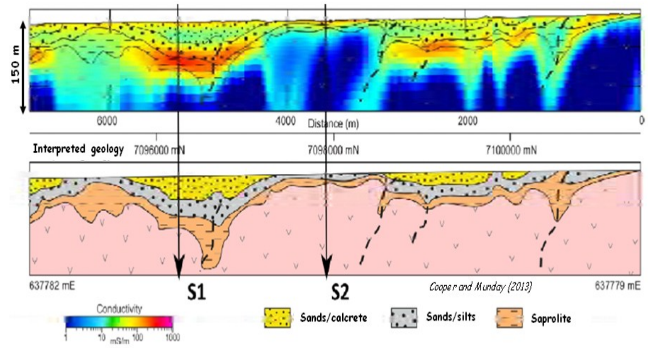

Figure 8: Shallow resolution of SPECTREM^{Plus} data (modified from Cooper and Munday, 2013)

DATA PROCESSING AND INTERPRETATION

The focus of development for many AEM systems in the last few years is to generate the best possible geological information in often complex terrains.

Over the last couple of years, Spectrem Air specifically focused on extending the range of conductivities using the in-house sum-of-exponential (SOE) approach in conductive environment as well as extracting up to 40 user-selected channels in a decay curve using a new multi-window algorithm. Another emphasis is on the recognition of induced polarisation (IP) effects in AEM data and how to correct the EM data and extract the information has seen significant development.

The approaches have all contributed to a more detailed integration of geophysics with geology. An example of SOE processing and a 3D model of a recent survey are shown in Fig 9 and 10 respectively. A deep conductive target is now clearly visibly on the SOE processed data. The integration of AEM results with some ground AMT data clearly defines a new kimberlite target.

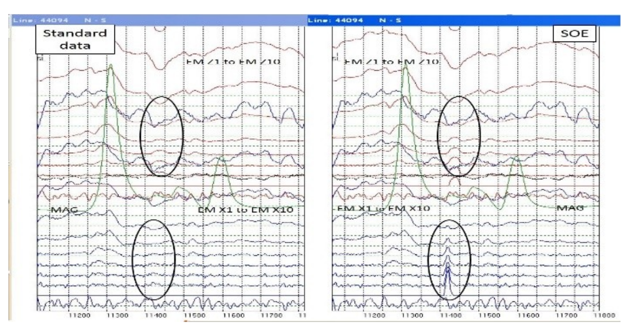

Figure 9: SOE for better detection of targets.

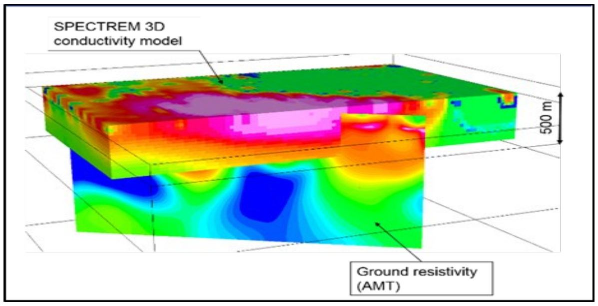

Figure 10: 3D modelling and data integration.

Additional work is now focused on passive EM information from the recorded full-waveform data, which will add further details to the interpreted geological results.

TRENDS IN AIRBORNE EM

There are currently only two large loop fixed-wing AEM groups in operation and a range of heli-borne systems available.

The general trend taken by Spectrem Air and CGG Multi-Physics (personal communications) is fairly similar in terms of improved discrimination of geological features, increased penetration, enhanced signal to noise, reduced cost and improved quality of inversions. Both groups have been working on improving the quality of the power spectrum - power in the high frequencies is most important for conductivity discrimination. In all cases, system geometry measurements are most critical in the correction of readings required for better inversion of data which could significantly change how AEM data is used. The noteworthy improvement in 3D inversion and integration (constraints) with other data is becoming readily available (an example is the CGG Multi-Physics Imaging Group).

The development in helicopter AEM technologies is also following a similar path and the discrimination of superparamagnetic (SPM) effects and better early time measurement for shallow applications are just some of the focus of the Geotech Ltd and SkyTEM R&D teams.

CONCLUSION

Aa range of substantial advances have been generated by the various airborne electromagnetic service providers over the last few years. The focus has been on increasing dipole moment, better multi-receiver sensors and improved processing of data. Recognition of induced polarisation effects has also resulted in better modelling of conductive targets.

The recent development of the SPECTREM^{Plus} system described in this document resulted is in the very fast turn-off of a 100% duty cycle transmitter and good calibration of data that will allow for concurrent acquisition of both shallow and deep information. The recording of better magnetic data through the development of a new towed bird will result in a significant reduction in the acquisition cost of high quality airborne data for exploration companies.

While the increased dipole moment of the new SPECTREM^{Plus} system has significantly improved the mapping of deep features especially under cover. New post processing techniques are now allowing for better extraction of high resolution shallow geology. This makes the system the ideal platform for mapping the Earth at all scales down to at least 800 metres in most environments.

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