New developments with the HeliSAM and UAVSAM systems, for use in mineral exploration

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SUMMARY

Since 2016 Gap Geophysics Australia has been developing and testing a commercial UAVSAM system. Originally completed in 2017, a series of follow up miniaturisation development steps and trial work were completed.

This system is now commercially ready and the UAVSAM system is capable of both EM and MMR acquisition between frequencies of 1 – 12.5 Hz. Gap has completed a series of trials to confirm the operational parameters of the platform and inherent noise floor. These trials included comparing many commercial UAV systems and their benefits for geophysical exploration. The UAV system chosen is a multicopter capable of flight times of 1.5 – 2 hours using a hybrid motor.

In miniaturising the SAM system for UAV deployment, Gap has also produced its "Generation 2" HeliSAM system. This system now is completely contained within a slung bird, and no longer has any rack mounting inside a Helicopter. This system has completed commercial work, most recently in Greenland for massive sulphide exploration at deep depths.

Key words: SAM, UAV, HeliSAM, Total Field, B-Field

INTRODUCTION

Sub-Audio Magnetics (SAM) was a method developed to sample both the electrical and magnetic properties of the earth and is described in Cattach et al. (1993) and Boggs et al. (1998). SAM has been used for a wide range of geophysical exploration, mapping, environmental and unexploded ordnance (UXO) applications for many decades but is principally used for mineral exploration.

SAM can be deployed in two principal modes, galvanic (magnetometric resistivity - MMR) and inductive (electromagnetic – EM) in numerous deployment styles. These include salt lake sled, walked acquisition, stationary tripod, helicopter system and now UAVSAM. Galvanic deployment involves laying a dipole wire, and emplacing electrodes to facilitate direct current injection into the earth. Inductive deployment involves using fixed or moving loops and measuring the secondary induced response from geophysical targets.

In recent times, SAM has been robustly tested at test ranges in Australia, or on exploration projects to push the boundaries of what is technically achievable with total field magnetometry. Commencing in the early 2010s, SAM was deployed at the Forrestania Test Range in Western Australia to test "SAM EM" a version of continuously acquired EM data with ground loops. Over subsequent years, SAM was deployed at Forrestania to trial "SAMSON" a low-frequency variant with a fixed tripod and stationary receiver to push the depth of exploration of EM technologies. In 2017, HeliSAM EM was deployed to see how low-frequency airborne total field EM receivers could resolve, and test targets not previously detectable from the air. This most recent test went on to win a highly regarded industry award through the Australian Exploration Geophysical society for innovation.

Prior to COVID, Gap Geophysics Australia (Gap) had been making strides to commercialise the latest versions of HeliSAM and UAVSAM to further push these innovative boundaries. This paper aims to explain the current latest developments in both HeliSAM and UAVSAM and what Gap believes to be the next horizons for deep and high-resolution EM exploration.

TECHNOLOGY BACKGROUND

For many years Gap has been conducting their proprietary HeliSAM B-field surveys, mostly in Australia and Canada, and more recently in Greenland. These have been both galvanic dipole (MMR) and inductive loop, total field electromagnetics (TFEM). For ground dipoles, these can vary from small dipoles (on salt lakes) to minimise inductive coupling response from the amount of wire deployed, but in resistive overburden, one dipole can extend for up to 20 km. In the inductive case, loops commonly vary from $200m^2$ for MLEM and $1\text{-}2km^2$ for larger FLEM surveys. Gap also can spectrally separate ground EM response from galvanic channelling, referred to as galvanic source EM (GSEM) to reflect the galvanic and distinct nature of this EM response from conventional EM measurement.

Larger EM loops are optimised for maximum depth of survey and for energising massive deep conductors, such as nickel sulphides. This means that shallower targets are not imaged, but that is the point. Other commercial EM systems can already achieve this shallower detection, and deep exploration is the focus. A helicopter-borne bird incorporating a magnetometer as the main receiver, is towed usually about 30 metres above the ground, and itself positioned 30 m below the helicopter, flying at speeds of about 50 knots. This method has proven to be very successful, with one notable achievement being the imaging of the approximately 1 km deep Lalor ore body in Ontario Canada. It also resolved all deep Forrestania test targets, modelled down to 600m through very conductive overburden weathering response.

In contrast to this, the same magnetometer comprising the Geometrics G-822A Cs Vapour Sensor, coupled with the proprietary Gap TM-7 SAM receiver has been packaged into a much smaller bird, light enough to be carried by any UAV capable of carrying a 5 kg payload. This combination provides an opportunity to conduct quite different surveys (referred to as UAV SAM), using grids of the order of hundreds of metres targeting shallower conductors that can be imaged at a much higher resolution, while still allowing the same low frequencies used with the larger scale HeliSAM system (typically in the range 3.125 Hz – 12.5 Hz). This same miniaturisation development has facilitated the completion of Gap's Generation 2 HeliSAM system, which has finished its first deployment on deep inductive exploration work in Greenland.

The SAM method requires a fast-sampling magnetometer such as the TM-7 (capable of 9600 samples per second) to measure the EM decay as a B-field time-series, using appropriate time-domain filtering but described here in frequency domain terms, to separate the earth-field (near-DC) component from the Total-Field EM decay component manifested at the odd harmonics of the chosen transmitter frequency. Successful separation of these two components requires a compromise in the choice of transmitter frequency, sensor height above the ground and survey speed across the ground.

With the large-scale HeliSAM surveys, the 30 m sensor height permits a fast survey speed (50 knots), because that combination will attenuate the near-DC earth field enough to ensure a clean measurement of the EM decay at the first harmonic (equivalent to the transmitter frequency) of approximately 3.125 Hz. In contrast, UAV SAM approach might be flown at 5 to 6 knots (10 kph or 2.7 m/s) allowing a sensor height of 10 to 20 metres and a transmitter frequency as low as 1-2 Hz. The lower sensor height would provide greater resolution, and the lower frequency ensures good penetration into a conductive overburden, as well as providing strong responses from shallow conductors.

Figure 1. Gap Geophysics Australia "Generation 2" HeliSAM bird.

Figure 2. Gap Geophysics Australia "Generation 2" HeliSAM bird.

DEVELOPMENT AND SYSTEM DESCRIPTION

Over the years Gap have trialled a number of UAV's, including gas-powered helicopters and battery powered as well as hybrid multicopters. Only helicopters and hybrid multicopters have sufficient capability to fly a 5 kg payload for 1.5 hours, which is seen as highly desirable to ensure good survey productivity. A single small EM grid can be covered with a single sortie, thereby minimising movement of ground-based equipment including the geophysical transmitter, UAV ground base, and a base station for the DGPS GPS and magnetometer. Multicopters have shown they can operate as well as helicopters in windy conditions so long as they are large enough, and are Gap's preferred option at the moment, with one significant advantage being their simplicity, reliability, redundancy (for example a 6-rotor hexicopter can still fly if one engine fails). Helicopters can be operated in stronger winds, but they require a much higher operator skill level for flight preparation and maintenance.

The minimum requirement for any UAV apart from endurance and payload include dual RTK DGPS for accurate navigation (0.5 m or better), a Laser Altimeter or Radar for accurate measurement of height above the ground, and optionally video as an aid for situational awareness or manual flight control. UAV flight controllers having the terrain following capability also adds an extra level of operational control. All these capabilities will ensure the UAV is able to accurately follow the pre-determined survey path, and features such as 'terrain following' provide a means to safely survey with the sensor close to the ground, thereby maximising resolution. A significant factor here is the use of an accurate digital terrain model that can be utilised as part of the flight controller's precise navigation. This ability is especially useful in rugged terrain, which might be one place where the UAV can be safer to use than the full-sized HeliSAM system.

One approach being considered for rugged terrain is to conduct a first survey with a Lidar (using the same multicopter flying higher with wider line spacing) to obtain a very accurate digital terrain model, that can then be usilised for the UAV SAM TFEM survey with an easy loading of the data into the mission planning software and flight controller for efficient autonomous flight. Additional aids such as the forward-looking video can provide the means for the UAV Controller to intervene for manual flight if it becomes necessary, or in the case of emergencies, say due to system failure.

The instrument bird needs to be suspended at least 20 m below the UAV to minimize interference from the UAV engine. The enclosure is shaped to have no lift surfaces and with some small amount of drag and a wind vane tail to ensure 'weather cocking' so it will self-orientate in a direction representing the resultant of the two main forces of wind and UAV flight direction. This will allow it to fly in a stable manner, to counteract the relatively low flight speed and light weight. One of the great benefits of using a total-field sensor is that the direction of the sensor relative to bird heading is inconsequential.

In addition to the Cs Sensor and TM-7 SAM receiver, the bird also includes its own laser altimeter, RTK DGPS and INS/AHRS system that all combine to provide accurate position, velocity, acceleration, and orientation of the sensor itself, all of which will be different to the UAV flying 20 m above. Lithium batteries and CF Card storage provide for a system capable of operating continuously for at least 2 hours, well above the typical 1.5-hour UAV flight time.

TESTING

Gap first developed its UAVSAM system back in 2017. These preliminary tests focussed on determining the operational limits of the system and in particular the noise parameters of the platform. The miniaturised TM7 UAV system has an operational bandwidth of 4800 Hz and maximum sample rate of 9600 Hz but can down sample this if required. The total field sensor has an inherent noise floor of 1 pT/root Hz or 2.8 pT RMS (1 - 10 Hz). A visual representation of this noise floor is shown in Figure 3, and test data collected in Figure 4.

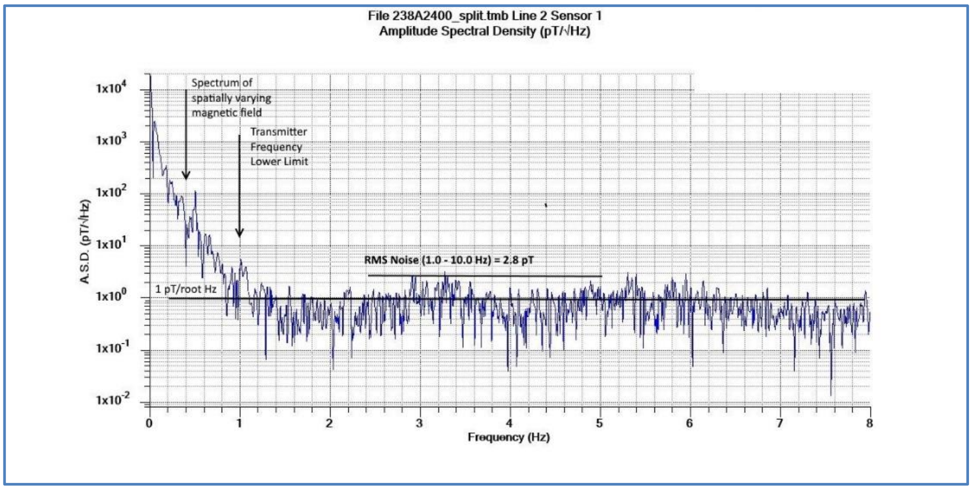

Figure 3. Amplitude Spectral Density of Single Line in 500 m Grid

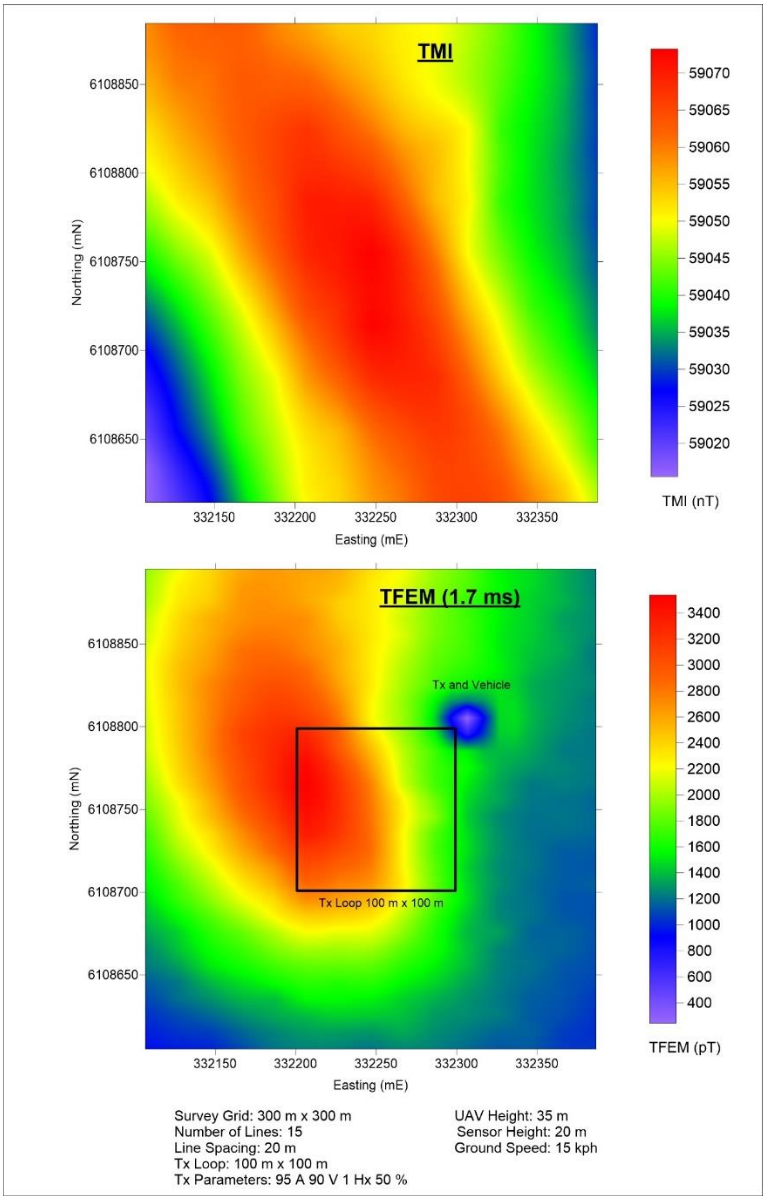

Figure 4. SAM TMI and TFEM Images of 300 m x 300 m N-S Grid

The latest testing in Canada has been focussed on testing the frequency limits of the UAV system. Gap has modelled sensor height as a function of ground response, and the limits of frequency deployed. There are several ways to approach this, particularly as the UAV platform is capable of Magnetics, SAM (MMR) and EM acquisition. This versatility is one of the key strengths of the system. In the EM case, given the deep depths of exploration, a sensor can be flown higher to mitigate ground noise response, thereby allowing lower frequencies to be used. Gap believes we can effectively collect hovering or stationary EM measurements with the system, or by flying slowly achieve 1 Hz in continuous flight. For the galvanic case, the survey frequencies are generally much higher to enable high quality spectral separation of Mag response, so the height of the platform is less consequential on frequency selection. Frequencies for MMR surveys would normally be on the order of 3.125 – 12.5 Hz.

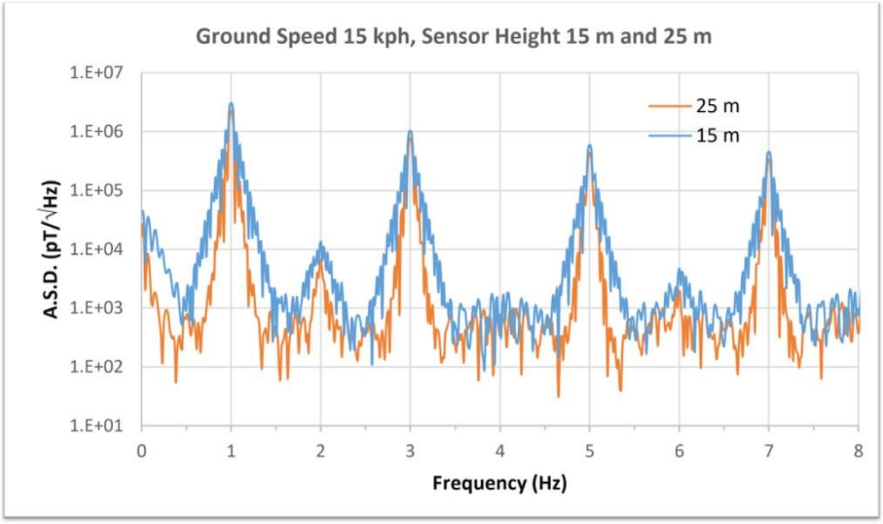

Figure 5. Sensor height comparison as a function of ground response and transmit frequency

POSSIBLE SURVEY METHODS

This UAV platform will open new, more efficient, and cost-effective ways to collect galvanic SAM and EM data. The immediate benefits are in minimising ground impact. A key criterion for many mid-tier and major mining houses these days and to provide more sustainable exploration techniques. In a basic example, replacing ground MLEM with a UAV system would cut footprint on the order of 50-75% with the only groundwork being in laying loops spread widely spaced. There is also great potential in replacing ground sensors on FLEM (or MLEM), such as regions with hazardous environments or difficult terrain. Initial work has been started on investigating swarmed receivers, to deploy multiple UAVs from a single pilot controller with spotters in support.

Gap has plans to conduct commercial UAVSAM MLEM trials with industry partners in comparison to previously acquired conventional MLEM data. MLEM is commonly considered the industry standard follow-up to AEM anomaly detection. This approach assumes that conventional AEM systems can penetrate deeply enough to initially detect anomalies. Often these surveys are flown over regions of thick conductive weathered cover (at least in Australia), which renders conventional AEM ineffective. These regions then become “blind” to EM detection from the air at least. Gap proposes UAVSAM MLEM as an effective option to open these regions with higher-powered MLEM and high-resolution surveys to deal with this difficult challenge.

Conventional AEM systems are effectively limited by the dipole moment of their transmitter (on the airframe), the sensitivity of the receiver instrument, and any corrections required (to the waveform, for rotational noise, for example). By deploying a higher sensitivity system on either Helicopter or UAV, coupling it with a total field magnetometer (allowing low frequency, continuously logging receiver), these surveys can extend the effective search radius at depth to deeper than 500m efficiently. Adding additional value to this approach are Gap’s large EM transmitter systems (HPTX series) and portable (MVTX transmitter and PS30MV 3-phase power supply) system. This is the world standard for high-powered EM surveying through conductive cover, using low transmitter frequencies. This combination has already been field proven to achieve 1-2 Hz acquisition frequencies of high-quality EM data, as described in Cattach et al (2018).

By moving this concept to a UAV system, Gap believes we can successfully achieve even lower transmit frequencies while achieving efficient and cost-effective production with high-quality data. A transmit frequency of 0.5 Hz for a moving platform has been proposed, although conceptually, data could also be acquired in a “hover mode” similar to the SAMSON tripod acquisition. This concept would be limited to stacking time, any wind effects primarily, otherwise, lower frequencies still could be achievable.

It is not only possible but more efficient to acquire MLEM survey data using larger loops (400 x 400m) and a UAVSAM total field sensor. Each loop would be placed approximately 300-500m apart to make use of the UAV system's higher dipole moments and longer flight lines. This system would then act as an "anomaly detector", aiming to return to any anomalies and reposition loops if any anomaly is recorded. Each loop would have approximately 2km lines in an orthogonal pattern (perhaps 3-4 x 2km lines N-S and E-W for each loop). The loop would then be moved ~300-500m and repeated across a large area. This loop configuration is optimised to capture deeper wavelength anomalies for targets up to 500m. By deploying larger loops, longer acquisition lines should be used to exploit the larger loop moment generated.

A 1.5 – 2km line (3-4 x wavelength) should be enough to sample any anomalies in and outside the loops. Of course, this is only one example, and depends greatly on the geology being explored. The benefit of this approach is that it can be configured to any loop size, or loop spacing required to effectively interrogate the area.

Survey Mode	Sensor	Transmitter	Scope	Production	Depth sensitivity
Ground MLEM*	Scalar (SAM/SAMSON), Vector (Fluxgate, SQUID, Coil)	High current, low power, Low voltage (50-200A). E.g. Gap EMTX-200 / DC10LV-2	Lines are generally 200 – 400m apart. Stations 100-200m apart. Often Slingram collected to offset near-surface effects	1.5 – 2-line kms per day	< 300m
Ground FLEM**	Scalar (SAM/SAMSON), Vector (Fluxgate, SQUID, Coil)	Higher voltage, high current, high power. E.g. Gap HPTX70/80 series	Generally multiple large loops per target, depending on depth, for multiple coupling orientations	Approximately 1 loop (500 x 500m) every 2-3 days (assuming approximately 100-150 stations)	Depends on loop moment and overburden, but generally < 800m
Airborne EM	Scalar (SAM/SAMSON), Vector (Fluxgate, SQUID, Coil)	High current, low power, low voltage (multi-turn loops)	Effectively Airborne MLEM	~500 line kms per day for Heli, more for Fixed Wing	< 200-300m
UAVSAM MLEM***	Scalar (SAM/SAMSON)	Single loop, high current, high power, medium voltage	Multiple 400 x 400m loops per day. Approximately ~20-30 line kms per loop in two orientations.	2 line kms per day, high resolution both inloop and out of loop.	Target range 100 – 600m depth

Figure 6. Comparison of conventional EM methods with UAVSAM

* MLEM coverage is generally along line and constrained to in-loop / out-of-loop Slingram measurements. Narrow band of data / coverage and wide line spacing for cost-saving measures.
** FLEM coverage is constrained to already detected anomalies, generally from AEM surveys. Slow to deploy loops. Data is generally rapid to acquire but still restricted to measurements every 50-100m. Approximately 150 stations per loop, depending on loop size.
*** UAVSAM MLEM coverage aims to take the best of both methods and boost coverage and resolution. Each loop would effectively cover ~4km^2 of survey area. Each day, 2km of along line surveying and multiple loops would result in ~6-8km^2 of effective coverage at great detail and depth of penetration.

CONCLUSIONS

Recent testing and development have produced a commercially ready UAVSAM system, able to be used in multiple modes of operation. Gap can deliver UAVSAM surveys for galvanic dipoles, EM loops (MLEM or FLEM). These surveys can be configured to the application but are otherwise capable of surveying between 1 and 12.5 Hz transmit frequencies.

The benefit of a UAV system is less impediment by terrain, or ground hazard (for example, unstable or steep terrain, faults or cracks, or poor access, such as surveying over lakes or tailings dam). These surveys will also be low impact, and sustainable ways of exploration.

UAVSAM data will be incredibly high resolution, with great redundancy post stacking. With the ability to collect continuously recorded data without needing to pause. Gap's latest system will utilise a UAV system capable of sorties between 1.5 – 2 hours of operation.

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