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Design and testing of ARMIT magnetic field sensors for EM systems

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SUMMARY

We have designed and tested compact magnetic B and dB/dt sensors suitable for geophysical operation through monitoring the current and voltage induced in a test conductor within the sensor. Laboratory and field tests confirm that a 50 cm long sensor of mass less than 1 kg can be constructed with noise levels between 1 pT and 10 fT per √Hertz over the 10 Hz to 100 kHz bandwidth respectively. The sensors are robust, and a rigid 3 component mounting box with accelerometer orientation permits rapid field deployment without the need for levelling

Key words: Electromagnetic, Sensors, Coil, Perfect conductor

INTRODUCTION

There are many B and dBdt sensors (Boll and Overshott, 1989) in use in geophysics today, with some properties of common devices summarised in Table 1. Geophysical sensors have an intrinsic (eg shielded room) noise level but must operate outdoors, and invariably "see" a variety of "unwanted signals". Of these unwanted signals, sferics are the most ubiquitous in the 10 Hz to 100 kHz band. Although each sferic is a transient event, over periods of seconds they can be treated as a stationary ensemble and their power spectrum defined. Summer afternoons are found to have much higher levels of detectable spherical activity than other periods, as it is then that thunderstorms are within a few thousand km.

Crudely then, good geophysical sensors can fall into one of three categories: a) ultra-low noise sensors designed to measure spherics and their resultant Schumann resonances, possibly to be used as MT sensors with remote and local reference noise subtraction; b) sensors whose intrinsic noise levels are lower than sferics in most cases, designed to be used on their own, and c) noisy sensors. The rationale for b) being "good" is that if spherics set the survey noise level, all we need is a sensor that does not increase the noise. Such a sensor would be useful if it can be made rugged, lightweight and inexpensive compared to an MT sensor.

The literature provides typical defines spheric and sensor noise levels, and Figure 1 is a summary plot of noise power with data obtained from various sources.

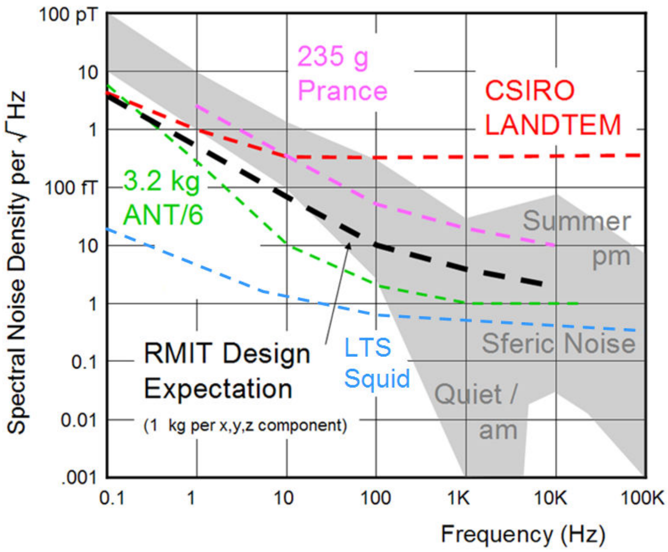

Figure 1 Typical Sferic noise range (grey), and specifications of miniature Prance et al current sensor (magenta), CSIRO Landtem SQUID sensor (red), Zonge ANT/6 AMT sensor (green), and target ARMIT sensor (black). Fluxgate sensors have noise levels about 5 pT/√Hz and lie well above the sferic noise. LTS noise levels on this plot are lab levels, and underestimate those achieved in the field

The Abitibi-RMIT (ARMIT) design goal was to produce a B and/or dB/dt sensor that has lower internal noise than sferics in the "quiet times". The black dashed line above specifies a sensor that is:

a) One order of magnitude less noisy than typical summer afternoon/evening sferics.
b) Less noisy than quiet sferics in the 0.1 to 100 Hz range.
c) Designed to have robust components and weigh approximately 1 kg per component, or 3 kg for a 3 component system.
d) Designed to be compact and low to the ground to minimise wind noise.
e) Highly linear over 0. 1 Hz to 10 kHz band.

DESIGN

We chose to base the ARMIT coil design on a modification to an induction coil operated as a current source. Basically, without giving away the details, we constructed a “perfect conductor” in the engineering sense. In practice this means that we constructed a conductor inside our cylindrical tube whose time constant is longer than any target time constants of interest. For an inductor, the time constant is given by the L/R ratio, and our aim was to get this value up to 10 seconds. We achieved this in a 500 by 20 mm package with some difficulty, using recently developed nano-engineered materials. Conventional electronics was then used to measure the induced current (or its time derivative) in our perfect conductor. The induced current is directly proportional to any changes in B through Lenz’s law, and an alternative current derivative measurement is directly proportional to dB/dt.

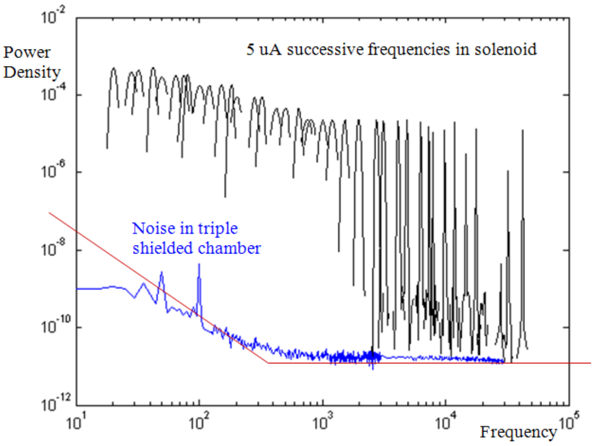

Figure 2. Early test of a prototype sensor to establish relationship between signal and noise. Each black peak corresponds to a power density equivalent to an amplitude of 1 pT per sqrt(Hz). The triple walled chamber shielding effectiveness decreases below 300 Hz.

Because the sensor is a perfect conductor, it has perfectly flat bandwidth at high frequencies until the wavelengths of EM radiation become less than 1 m (up to frequencies of 300 MHz). One of the biggest challenges in laboratory testing of the sensor was RF radiation becoming demodulated through system non-linearity and affecting our desired noise levels. To counter this, we double screened the sensor with a standard foil shield, plus constructed the rigid outer tube for the sensors from electrically conductive carbon-reinforced fibre composite, the thickness of which material in conjunction with the foil reduced the upper bandwidth to several tens of kHz.

Noise levels in the ARMIT sensor were lower than design aim in our triple shielded “zero gauss” chamber, but slightly higher in a field test in Utah (Fig 3) comparing B field sensors. The field test however was constrained to use an imperfect substitute to the nano-engineered core, which both increased the noise level in the field test and reduced the system bandwidth (Fig 4).

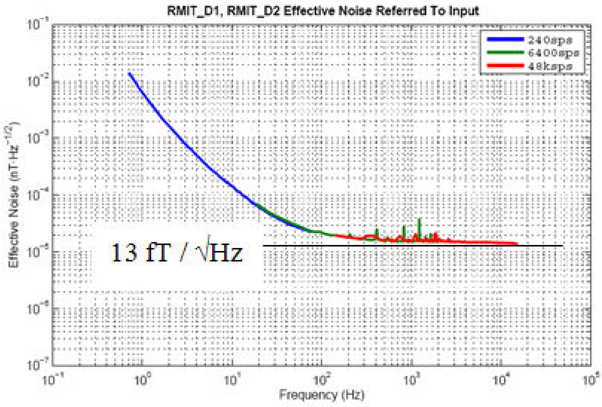

Figure 3: Noise level of ARMIT sensor measured in Utah. Due to DAS limitations, the noise at low frequencies (<10 Hz) is overestimated on this plot.

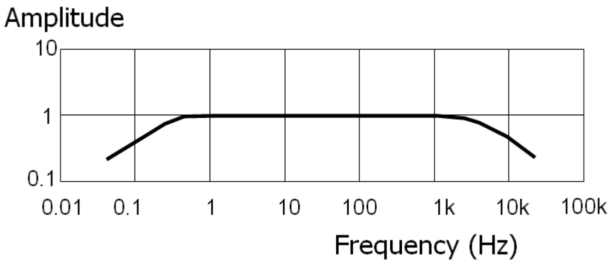

Figure 4: Amplitude sesntivity as a function of frequency to show 0.1 to 10 kHz bandwidth for the sensor

Figure 5: Three component ARMIT sensor in the field. The upper case contains accelerometer and orientation sensors so that measured data may be numerically rotated to the x , y, z or E, N, UP directions

The sensor has commenced field testing as a 3 component TEM sensor at the time of submission of this abstract. (Figure 5)

CONCLUSIONS

The ARMIT sensor is quieter than published noise figures for HTS sensors and spheric noise, a 3 component rugged compact sensor weighs 3 kg is low to the ground and can be 'firmly placed' on the ground without the need for levelling.

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REFERENCES

Boll, R and K Overshott, 1989, Magnetic sensors Vol 5; VCH.

Sensor / Cost (figures)	Pros	Cons	Supplier Examples
LTS $$$$$$	Lowest noise Flat Response	10 g sensor with 10 kg excess baggage Liquid Helium Delicate	IPHT Jena exclusively to Anglo
HTS $$$$$	Flat Response	10 g sensor with 10 kg excess baggage Liquid Nitrogen Delicate Flux trapping and slow reset	IPHT Jena exclusive to Discovery Int. Geo. CSIRO exclusive to Outer-Rim
Feedback Coil $$$$	Rugged	Heavy, Limited bandwidth, Long	Schlumberger Zonge Lamontagne
Open Induction Coil (V) $$$$	Rugged, cheap	Big if low-frequencies required. 1/f sensitivity limits low frequency performance	Geometrics Geonics Large Loop
Closed Induction Coil (Current) $$$$	Should be rugged Could be cheap	Very strict electronic constraints. Heavy to get low bandwidth	Meda Phoenix? Prance (medical)
Fluxgate $$$$	Flat response	Bandwidth < 2 kHz, Noisiest useful sensor	EMIT Bartington
Optically Pumped Magnetometer $$$$$	Flat response	Bandwidth limit 1 kHz, Component parallel to earth's field only	GAP