The Impact of AEM Receiver Noise Levels on Detection, Discrimination and Resolvability of Conductive Targets

Magdel Combrinck
Geotech Airborne Limited
121 Rosen Office Park, 37 Invicta Rd, Midrand, SA
magdel@geotechairborne.com

SUMMARY

Lowering receiver noise levels of EM systems has the same benefits as increasing the transmitter signal, because detectability, discrimination and resolvability of target responses improves as the signal to noise ratio increases. Unfortunately the peak dipole moment (where peak dipole moment is considered to be the product of the peak current and the effective transmitter loop area) of TEM systems is often still perceived as being the most significant factor contributing to the signal to noise ratio. The importance of also taking into account the excitation waveform pulse width and shape when determining target response is well published. However, the quantitative effects of reducing receiver noise levels have not received much coverage in literature. Modeling experiments using real VTEM system noise samples from 2006 and 2009 indicates that a four times reduction in system noise amplitude can improve detectability of targets up to 100 m deeper and also enables target conductance and geometry to be modeled as accurately for targets up to 150 m deeper. These improvements are better than can be modeled with a simulated increase in peak dipole moment giving the same signal to noise ratio. This is most likely due to the fact that the real character of noise should be taken into account and not only the standard deviation.

Key words: VTEM, TDEM, electromagnetic, noise

INTRODUCTION

Achieving the highest signal to noise ratio is a common goal in all geophysical instrument and survey designs. Dealing with Time Domain Electromagnetic (TDEM) equipment, the signal can be increased by employing a larger peak dipole moment or a more effective waveform shape and pulse width (Becker et a., 1984; Liu, 1998). Noise reduction can be achieved for example through improved electronics, mechanical receiver stability, screening from external noise sources and stacking of data.

While these principles are valid for both ground and airborne EM systems, it is logistically more difficult to implement them successfully on airborne platforms. The brute strength approach of increasing the signal was favoured for a long time and it is not surprising that most AEM systems have reported increased peak dipole moments over the last 10 years as a means to increasing their marketability.

The objective of this study is to quantify the effects of reduced receiver noise levels on target detection, discrimination and resolvability using real noise statistics and samples. The VTEM system is ideally suited for such a study as it has shown significant reduction in receiver noise levels without any changes being made to either configuration or dipole moment.

Data from 24 surveys performed in Australia from 2006 to 2009 were analysed to determine an estimate for average noise levels during this time under field conditions. Measured noise samples from 2006 and 2009 were added to synthetic model responses generated with Maxwell software. These data sets were analysed to determine the impact of the different noise levels on the detection, discrimination and resolvability of targets. A comparison between the measured noise reduction and a simulated increase in peak dipole moment is also shown. The results indicate that for the VTEM system the four times reduction in noise levels provides better target resolvability than an equivalent increase in peak dipole moment.

Receiver noise levels are of special interest to clients contracting airborne EM technologies, because whereas an increase in peak dipole moment could result in additional operational cost, pulse waveform adjustments and improved receiver technology do not. Increased operating costs would be incurred when production flight time is reduced (or larger helicopters have to be used) in order to deal with the additional payload of larger loops or additional generators to increase peak current. In areas with severe topography or high altitudes, system size and weight become even more critical and when these factors limit the practical achievable peak dipole moment the advantage of using optimum waveform shape and low receiver noise levels become increasingly significant.

METHOD AND RESULTS

Synthetic model studies are often used to determine whether a marginal target (i.e. the target response is expected to be close to survey noise levels) would be detected and/or resolved with a specific TDEM system. In these studies synthetic noise is usually a randomly generated series and quantified only based on the amplitude of the standard deviation. However, system and survey noise does not always display this idealised random behaviour and for this study real noise measured from VTEM production surveys were used instead of randomly generated values.

Noise reduction in the VTEM system mainly came about with upgrades to include B-field measurements in 2007. This is shown in Figure 1, where average yearly noise levels are displayed from 2006 to 2009. The statistics were calculated from 24 production surveys done in Australia over this time period.

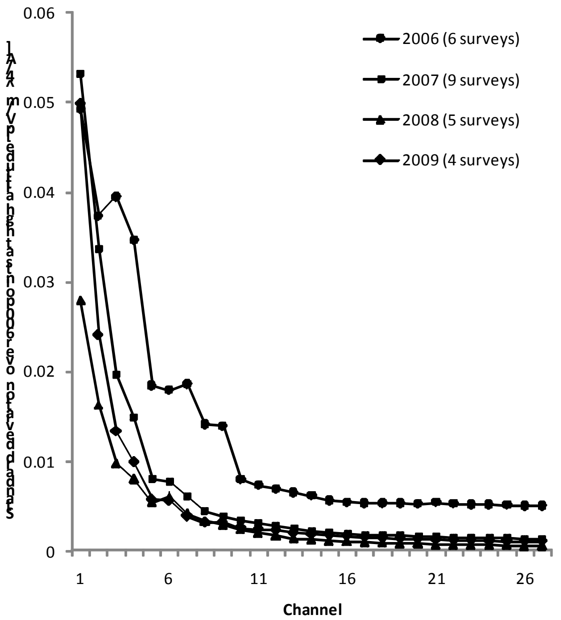

Figure 1. Comparison of VTEM noise levels from 2006 to 2009. Average noise levels for 2007, 2008 and 2009 surveys are shown as of the 2006 noise levels for each channel. (ch1 = 0.8 ms to ch27 = 7.8 ms)

For the purpose of this paper the 2009 noise levels were used as a representative average of the improved system noise compared to the 2006 noise levels that were averaged over 6 surveys.

Four representative noise sample data sets were extracted for use in modeling experiments, two each from 2006 and 2009 data. These are referred to as “Noise 2006a”, “Noise 2006b”, “Noise 2009a” and “Noise 2009b” respectively. The lowest noise level was on sample Noise2009b and noise levels are shown in Table 1.

Table 1: Relative standard deviation amplitudes averaged over the last 6 time channels of the four noise samples

Noise sample	Standard deviation of noise (pV/A/m^4)
Noise 2009a	0.0011
Noise 2009b	0.001
Noise 2006a	0.0044
Noise 2006b	0.0043

Lowering receiver noise levels increase the signal to noise ratio and an intuitive expectation is that reducing the receiver noise level by two should have the same effect as doubling the peak dipole moment. This is indeed inferred by Spies (1998) who approximates depth of investigation for TDEM systems as $d \approx 0.55 \left(\frac{nIA}{\sigma \gamma_V}\right)^{1/5}$ where nIA is the dipole moment, σ is the host conductivity and γ_V is the system noise amplitude.

However, we first need to define signal and noise amplitude, as well as detection, discrimination and resolvability before quantification of these factors are attempted.
The following definitions are used in this paper:

1) **Noise amplitude (per channel):** standard deviation of a noise data sample. When referring to measured VTEM noise, this will imply standard deviation over at least 600 points measured at high altitude
2) **Target response:** amplitude per channel as forward modeled with plate modeling software (synthetic) or as would theoretically be measured without any system noise
3) **Detection:** A target is considered detectable on channels where the maximum target response > 1 time standard deviation of the noise before filtering
4) **Discrimination and Resolvability**: the ability to retrieve accurate conductance and geometrical parameters of a conductor through inversion of data

For all experiments synthetic data were calculated with Maxwell software for a range of plate models and the respective noise samples added. The combined plate and noise responses were filtered with non-linear and low pass filters, using the same parameters as would be applied for spherics reduction under normal survey conditions. This is typically a 4 point non-linear with cut-off 0.0001 and 10 point low pass filter.

Detectability
Figure 2 illustrates the concept of detectability as defined in point (3) above. Synthetic data for a conductive plate dipping at 70 degrees with 2006 and 2009 noise levels for the first channel (ch 10) are shown in the top panel. The bottom panel indicates an anomaly that is considered to be at the limit of detectability after 2006 noise is added while the centre panel shows the same anomaly well above the detection limit with 2009 noise added. However, the smaller anomaly peak (right) which would be required for accurate resolvability of the target just falls below the defined detection level in this case.

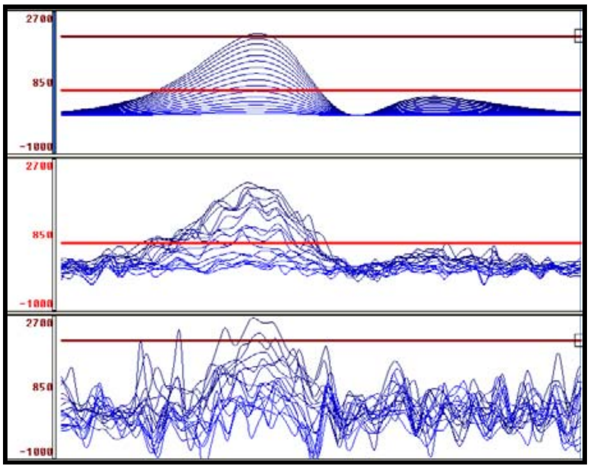

Figure 2. Example of anomaly detectability. The top panel shows the synthetic VTEM response (pV/m^2) for a conductive plate dipping at 70 degrees with depth to top of 350 m (channels 10 to 27). The 2006 and 2009 noise levels for channel 10 are indicated with the brown and red horizontal lines respectively. In the centre panel, a 2009 measured noise sample is added to the model response and filtered with standard spheric rejection parameters. In the bottom panel a 2006 measured noise sample is added.

Figure 3 shows the maximum target response on channels 10, 15, 20 and 25 for the same plate model at depths varying from 50 m to 500 m. The 2006 (brown) and 2009 (red) noise levels are also indicated for each of these channels. Applying these noise levels as the defined detection limits, it can be seen that the decrease in noise from 2006 to 2009 results in at least 100 m additional depth of detectability for this target.

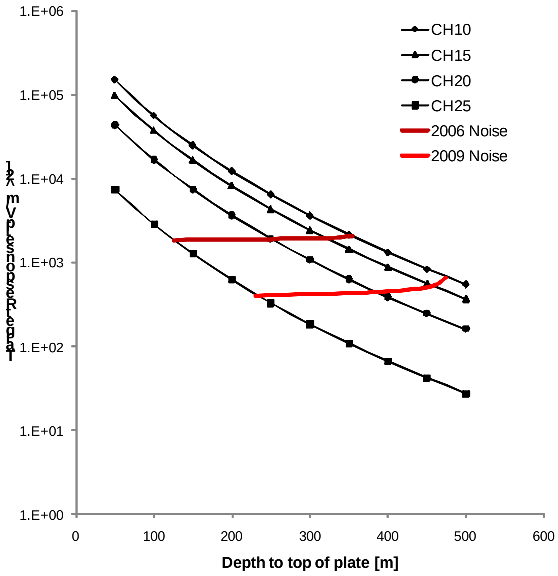

Figure 3. Maximum target response on channels 10, 15, 20 and 25 for a conductive plate dipping at 70 degrees are shown for varying depths. The 2006 (brown) and 2009 (red) noise levels are indicated for each of these channels.

Discrimination and Resolvability

Discrimination and resolvability of targets were tested through inversion of the noise contaminated synthetic model responses. The recovered conductance and geometrical parameters were compared with the known values used in forward modelling in order to quantify the modeling accuracy.

The plate models used were thin plates dipping at 70 degrees with 600 m strike length, 400 m depth extent and conductance of 50 S. The depth to top of the plates ranged from 50 m to 400 m. The "strike length", "strike/dip direction" and "northing" parameters were fixed during inversions as these can normally be determined when working with multiple lines of data. Depth, dip, depth extent, conductance and easting were allowed to vary without any constraints. A summary of these parameters are given in Table 2.

In order to work with a single relationship between modeling accuracy and noise levels a percentage modeling error was derived for each inverted model. This was done by calculating the average of the individual percentage errors of each of the inverted parameters.

The individual percentage errors for all parameters except "Easting" are given by:

$$Err\% = \frac{|Iv - Fv|}{Fv} * 100$$

Where Iv is the inverted parameter value and Fv the value used for generating the forward model. For the "Easting" parameter the normalization factor used, was not the forward model value of 10 845 m (which is arbitrary), but rather a fixed value of 200 m. This reduces the percentage errors to the same order of magnitude as the other parameters for most of the models. Also, depth to centre, instead of depth to top were used to calculate the error in depth so as not to give double weighting to depth extent errors. The average of the errors of all inverted parameters is termed the "average percentage error" and was used in this study as a single parameter approximation to inversion accuracy.

The four noise samples were added to 8 model responses of plates with depth to top varying from 50 m to 400 m. A total of 32 data sets were thus inverted and modeling accuracy was expected to decrease with both depth of investigation and standard deviation of sample noise. The results are shown in Figure 4. The 2006 noise data sets already show an increase in modeling error from 50 m to 100 m depth, while the 2009 data sets only start to show a real decrease in accuracy from 200 m and deeper. For depths shallower than 200 m the 2009 noise levels are too small to significantly influence the inversions. Once the noise levels become large enough to have an influence on the inversion, a linear trend is observed between modelling accuracy and decreasing signal. In the depth range where the linear trend is observed, the same resolvability can on average be achieved approximately 150 m deeper with the 2009 noise levels than with the 2006 examples.

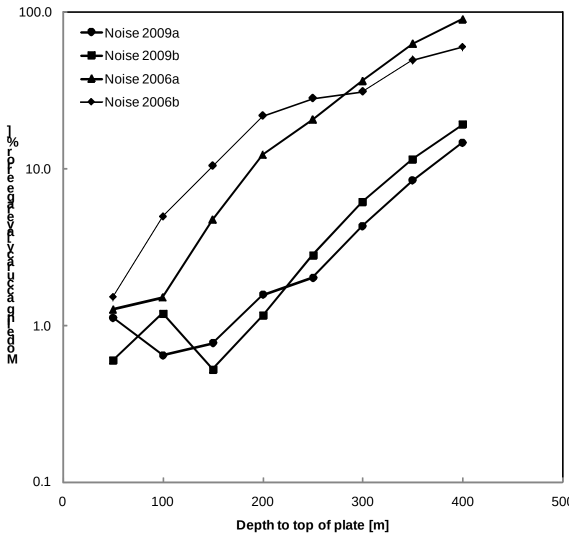

Figure 4. Discrimination and resolvability expressed as modelling accuracy for the 70 degree dipping plate model at different depths.

Comparing noise reduction to increasing peak dipole moment

Finally, the effect of an increased dipole moment on target discrimination and resolvability was simulated by scaling the amplitudes of the target response before noise were added to the synthetic data for the plate models. Channel 23 peak anomaly amplitudes and noise levels are used as representative signal to noise ratios as inversions were done on channels 20 to 26. Signal to noise ratios were varied from 0.25 to 4. The same inversion methodology was followed as in the previous section, and the results are shown in Figure 5. At signal to noise ratios less than 0.75 results become erratic with large modelling errors. There is an almost exact match between the 2009a and 2009b noise samples as would be expected as they have the same standard deviations. However, the 2006a and 2006b samples show very different results although they also have standard deviations very close to each other. The reason for this was found on closer inspection of the 2006b noise sample, where spikes were correlated with the smaller anomaly peak, leading to poor resolvability of the target. However, the 2006a noise sample still shows modelling errors higher than the 2009 samples even when the simulated signal to noise ratios are the same. The conclusion is that standard deviation of noise alone is not a sufficient indicator of the effects of noise on modelling of target responses. In the examples shown, the 4 times decrease in VTEM noise levels proved more beneficial than a simulated 4 times increase in peak dipole moment. This can most likely be explained as an improvement in the character of the noise as well as in a reduction of the overall noise amplitude.

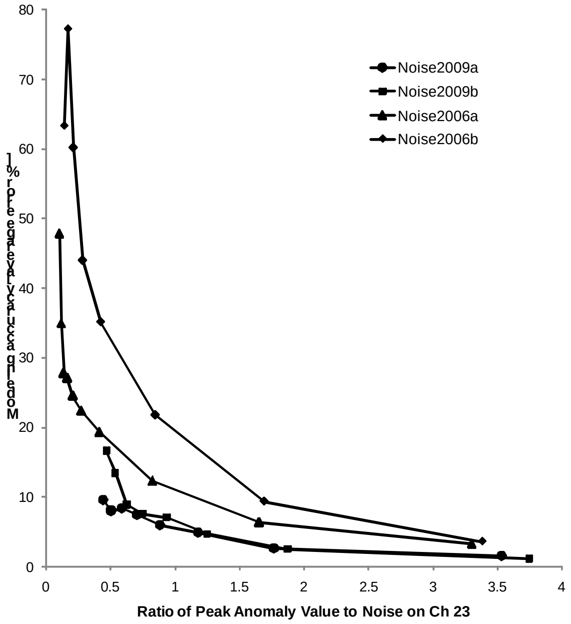

Figure 5. Discrimination and resolvability (expressed in terms of modeling accuracy) for the 70 degree dipping plate as a function of peak signal to noise ratio on channel 26 for 4 representative noise samples.

CONCLUSIONS

A series of plate modeling experiments were done using synthetic forward modelled data and real system noise samples. The effects of reduced noise levels on detection and modeling of target responses were investigated. Late time noise levels that were reduced by a factor of four, resulted in 100 m additional depth of detection and conductance and geometry could be retrieved with the same accuracy for targets up to 150 m deeper using the same inversion procedures. The improvements seen in modeling accuracy due to reduction of actual system noise is better than can be simulated with a numerically equivalent increase in peak dipole moment.

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Table 2: Summary of Maxwell plate forward model, starting model and inversion constraint parameters

Parameter	Forward Model	Starting Model	Free/Fixed during Inversion
Depth	50 m to 400 m	½ of forward model depth	Free
Dip	70 degrees	90 degrees	Free
Conductance	50 S	100 S	Free
Strike Length	600 m	600 m	Fixed
Depth extent	400 m	200 m	Free
Easting	10 845 m	10 800 m	Free
Northing	10 000 m	10 000 m	Fixed