

# Benefits of large channel capacity systems in electrical geophysics

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## SUMMARY

The merits and value of large channel capacity electrical geophysical systems reach further than simply collecting more responses per interpretation, which in itself is generally sufficient to justify the technology. In addition to that aspect are benefits related to productivity, SNR, and control or weighting of inversion and imaging data feed. No assessment of the cost/benefits analysis of pursuing large channel capacity technologies would have meaning without considering these many other side benefits.

This paper contends that data collected with high resolution, highly synchronous, distributed acquisition systems are ideally suited for advanced data manipulation based on superposition principles.

**Key words:** array conversion, distributed acquisition, superposition

## INTRODUCTION

The advantages of large measurement-channel capacities in seismic exploration systems have long been understood and pursued. The advantages of large channel capacity electrical geophysical systems (LCCEGS) have been a much more debated topic – the overall cost advantages seem less obvious to many in the case of electrical surveying and prospecting.

Several important aspects of the cost/benefit equation are overlooked in sceptical assessments of the advantages of LCCEGS. The viewpoints and prejudices that discourage development of increasingly larger LCCEGS, those that tend to favour the 8 and 12 channels that have been the standard for decades now, miss a suite of critically important advantages for having more channels.

The value of larger source/receiver multiplicity, or simply collecting more responses, is a primary consideration and the obvious focus. But there are also advantages relating to SNR, productivity and field procedure efficiency, as well as inversion and interpretation enhancements beyond simply having more responses. Some less obvious, but nonetheless important, advantages of LCCEGS are pointed out herein. Taken collectively, the impetus to press forward with developing increasingly larger LCCEGS becomes evident for most applications, both in engineering and in exploration applications.

## SOME TECHNICAL PRESUMPTIONS

In considering the many useful manipulations that one may pursue with LCCEGS data sets, three aspects form important theoretical underpinnings: (1) principles of linearity and superposition, (2) simultaneous acquisition/sampling of all channels, and (3) use of distributed acquisition (not multi-conductor cables).

The first principle is fundamental and warrants little further mention. The second is of critical importance in many manipulations but often overlooked or misunderstood. Collecting data from two sensors at different times usually has less information than when measuring both at the same time owing to generally shared or correlated noise in measurements, as shown in Figure 1(a) and (b). The importance of LCCEGS is further emphasized in considering superposition of current excitations as implied in Figure 2(a) and (b). Such potential and source dipole manipulations are generally referred to as array conversion or transformation.

The last item is of critical importance as well. Few of the presumptions are useful over a substantial bandwidth if the received voltages route through long multi-conductor cables similar to old-style seismic cables. A brief description of a distributed acquisition system and some of the advantages of simultaneous acquisition can be found in Garner and Theil (2000).

The point is that array conversion through the superposition of either excitation or receiving dipoles works well/efficiently when an entire line or 2-D array is measured simultaneously using distributed acquisition. Transformation of current excitation obviously only applies to the receiving channels available during the measurements – it is much better to be able to measure an entire line or 2-D spread simultaneously.

## SOME THEORETICAL MANIPULATIONS

A short list of interesting or potentially useful manipulations is provided below. It is by no means comprehensive. The intent is to illustrate the types of transformations that may be performed, but that may not be widely understood because of the dearth of LCCEGS. The manipulations are shown to illustrate a range of those theoretically possible. However, as always there are specific conditions and limitations that may make certain manipulations problematic. These considerations are addressed in the following section (Practical Limitations).

### Induced Polarization and Galvanic Resistivity

- Use a fixed “reference” current electrode anywhere along line (but preferably in the middle) and only move the other “roving” current electrode along line. A wide range of more standard arrays may be later calculated, including dipole-dipole (see Figure 2 (a)). Note that reciprocity as frequently used in dipole-dipole surveys only applies when potential and

current electrodes may be considered the same. If, as is handy with LCCEGS, current is injected in the middle of potential dipoles, then the resulting potential-left/current-right dipole-dipole responses are independent of the current-left/potential-right responses.

- In addition to the data set described above, if a single measurement is collected with current connected to the fixed reference and a sufficiently distant and orthogonal “back-current” electrode, then the data set may be converted to pole-dipole (current-left/potential-right), dipole-pole (potential-left/current-right) data (see Figure 2(b)). In other words, one can collect pole-dipole/dipole-pole data with only one measurement event involving a back-current. Hence, one can afford to use smaller back-current wire and be picking up and/or moving the back-current to then next survey site while finishing the line survey.
- If two lines are deployed and current injected into each line simultaneously, then dipole-dipole results for each line may be calculated independent of the broadside influence of the off-line current as shown in Figure 3(a). For this to work, the currents on each line can not be moved simultaneously, only one current electrode is moved at a time.
- Through summing all receiving dipoles along (a preferably long) line, plus adding two relatively long dipoles at each end, we can form a telluric noise reference potential bipole (Halverson, 1990; Halverson et al, 1989). (see Figure 3(b))
- In general and given a large enough measurement array, one may form one or more weighted combinations of receiving dipoles that minimize signal and maximize noise, thus affording telluric cancellation noise references.

#### Controlled Source EM

- Field operations may be devised whereby only one edge of a rectangular current source is moved instead of the entire transmitting loop. The results may be transformed to smaller loop excitations as shown in Figure 4(a) below. The same may be applied in reverse: combining multiple smaller square loops with shared edges to form one or more larger, and deeper sounding loops.
- Grounded line dipoles with four shared electrodes forming a closed loop, may be combined to form the equivalent of current loops as shown in Figure 4(a), if polarities are properly minded so that the current flow into and out of the ground is cancelled. By similar construction as indicated in Figure 4(b), potential dipoles that share electrodes may be summed to form the equivalent closed-loop induction EMF response. Hence, surveys may be configured for both grounded-line galvanic and closed-loop induction measurements at once.

#### Natural Field EM

- Measuring in-line contiguous (shared electrode) grounded line dipoles simultaneously on two parallel lines, along with one orthogonal dipole connecting the two electrodes at either ends of the lines, allows calculating the orthogonal electric field component for all electrode stations, but with a curved wire-path, as illustrated in Figure 5(a).

- Summing a long line of contiguous (shared electrodes) potential dipoles provides a long bipole signal reference that might serve well as a cross-reference signal to help suppress and/or reject electrode noise without the hassles of remote-site equipment and operations.

- Similarly to above, if a large number of (preferably 2 or 3 component) magnetometers are deployed, their measured outputs may be summed to provide a strong cross-reference to help suppress and/or reject vibrations noise, without the hassles of remote-site equipment and operations.

- Given a sufficiently (1) large receiving array, (2) high bandwidth, and (3) accurate phase (vis-a-vis sampling simultaneity), one might be able to determine bearing-of-source using beam-forming calculations and thereby help to isolate and distinguish local (noise) sources from distant plane-wave sources.

### PRACTICAL LIMITATIONS

Practical considerations may limit theoretical possibilities in many of the LCCEGS data manipulations discussed in the previous section. For the most part, these limitations stem back to: (1) ADC resolution/linearity and (2) ADC channel-to-channel accuracy.

Some manipulations entail combining two or more large amplitude signals to return an exceedingly small calculated signal/response. In these cases if the gain and phase accuracies of the channels involved are not either sufficiently well calibrated or matched, there will be bias in the resulting superposition result. Take for example the array conversion shown in Figure 5(b). The resulting signal might be many thousands of times smaller than the comprising measurements, depending on the distances. The demands on both amplitude and phase accuracy may be extreme. Note that we are interested in channel-to-channel relative accuracy, not absolute accuracy.

So in order to enjoy the benefits of these many manipulative transformations, large channel capacity systems need conscientious attention to both design and operations that afford extraordinary channel-to-channel calibration accuracies. The mention of operations playing a part is important. Time and temperature dependence make extreme calibration accuracy reliant on in-the-field, frequent and specialized calibration efforts.

A second and overwhelmingly important consideration is that all the controlled source transformations depend on normalizing to the excitation (current). It is essential that current be measured to the same or better resolution and accuracy as all other receiving channels. Hence, a large channel capacity should always enjoy an extremely high quality current transducer/monitor. This is an oft-overlooked aspect of array transformations. For the same reasons explained above, extreme accuracy, linearity, and resolution are all required in excitation measurements.

Note that there is a mixing of calibration errors in both phase and amplitude. Errors in amplitude or gain calibration will produce errors in array conversion chargeabilities or phase in

IP array conversions, even with perfect system phase calibration.

As a general rule of thumb, we suggest that gain accuracies worse than 0.01% will start to noticeably limit the range of useful transformations that can be safely performed. A reasonable goal that should be targeted is to ensure ultimate gain/amplitude accuracies of 10 ppm in large channel capacity systems. That is cost-effectively achievable, but such extreme specifications almost certainly demand specialized field procedures, equipment and frequent calibration measurements. Bear in mind that not all transformations are particularly sensitive to measurement accuracy.

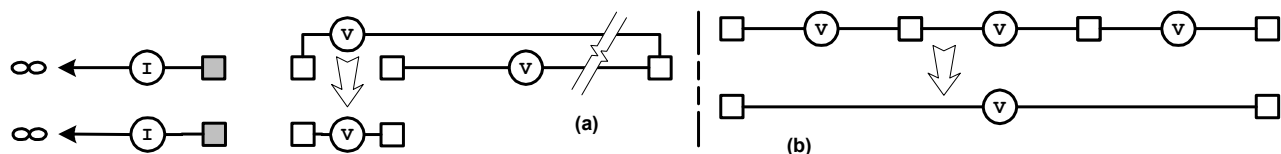
### TRANSFORMATIONS IN INVERSION

Ignoring productivity and noise rejection aspects, the value of such manipulations as discussed above may not be readily apparent. Such a “pessimistic” view actually shows reasonable insight because except for possibly improving SNR, these linear superposition transformations can not theoretically add information to the response pool. They all may be equated to taking a system of simple linear equations and re-combining them via linear operations - there are still the same number of linearly independent equations. So, for example, calculating cross-line electric field responses using parallel line simultaneous measurements as Figure 5(a), cannot produce truly new information. All independent information was already distributed throughout the component measurements.

Manipulations based on superposition and response linearity therefore essentially change the data weighting in the inversion process but do not add more information. It seems reasonable to expect that for a given data set (bearing in mind that this may imply thousands of source/receiver combinations) some linear combinations of responses might emphasize an inversion result that is more sensitive to deeper property variations, while other combinations could emphasize the locations of near-surface boundaries. In many regards this is the essence of many imaging. LCCEGS data enhance the strength and flexibility of current focusing approaches such as described by Cherkava and Tripp (1996).

The relationship between the effective inversion data weighting and the choice between the essentially infinite number of transformations possible will become an important aspect of optimising the value of large channel capacity surveys.

We expect the process of extracting all available information from LCCEGS data sets will force inversions to deal with the differences between bias errors (as related to calibration and survey position inaccuracies) and repeatability errors in response estimates. There are certainly ways of quantifying



**Figure 1. Superposition of grounded potential dipoles: (a) Convert pole-pole to pole-dipole thereby reducing noise, which is only reduced if both measurements are taken simultaneously, otherwise there will be a factor of  $\sqrt{2}$  increase in noise. (b) Form a larger dipole from summing contiguous smaller ones with shared electrodes. Noise from inner electrodes is canceled only if data are collected simultaneously. Results rival direct measurement given sufficient ADC resolution.**

and dealing with them both as opposed to simply ignoring one or the other. Future LCCEGS response estimates should carry not only repeatability error statistics, but also bias error statistics and inversions should properly deal with those data.

### CONCLUSIONS

There are significant advantages to LCCEGS. Principles of linearity and superposition afford useful data manipulations that are frequently dependent on the data across all channels being collected simultaneously. Many benefits rely in large part on high quality current monitors occupying at least one channel of controlled source surveys.

In the design of LCCEGS and operations, there are special demands placed on channel-to-channel relative calibration (amplitude and phase) that should be considered.

High resolution distributed acquisition systems provide vastly superior data quality compared to the traditional, 8-12 channel, multi-conductor acquisition systems, and are particularly well suited for data manipulation involving superposition techniques.

### ACKNOWLEDGMENTS

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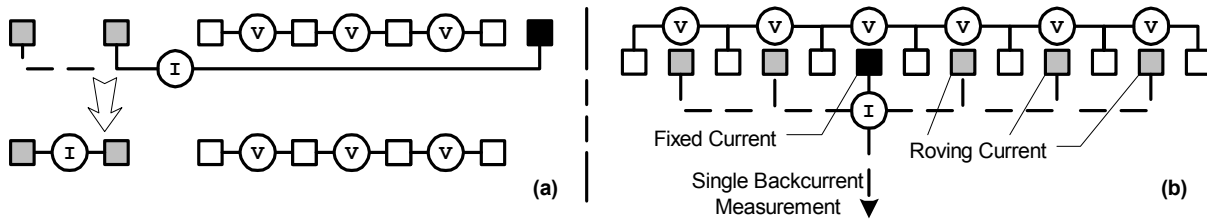


Figure 2. Superposition of current dipoles: (a) Transformation to dipole-dipole - the reference electrode may not move from one reading to the next for the transform to work. (b) Combining all data collected using the fixed “reference” current electrode and multiple roving current positions, plus one measurement with current between the fixed and a “back current” electrode, allows converting all data to pole-dipole (current left of potential)/dipole-pole (current right of potential) results. Responses resulting from two excitation transforms, as in (a) and (b), suffer roughly  $\sqrt{2}$  increase in noise but not necessarily an increase in SNR.

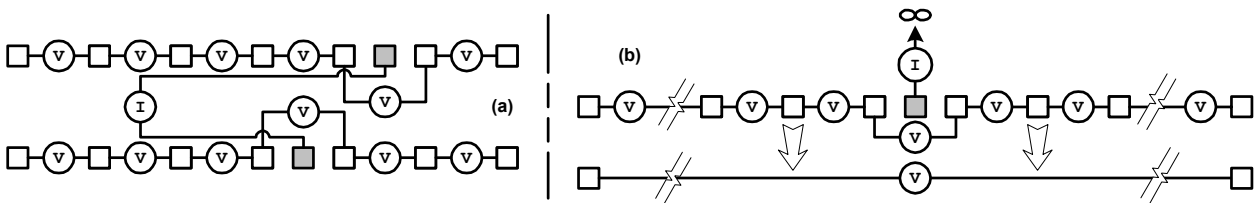


Figure 3. Grounded line manipulations: (a) Simultaneous collection of dipole-dipole results on two lines requires moving only one electrode at a time. (b) Long noise reference bipoles may be formed for purposes of Halverson (1990) style telluric cancellation.

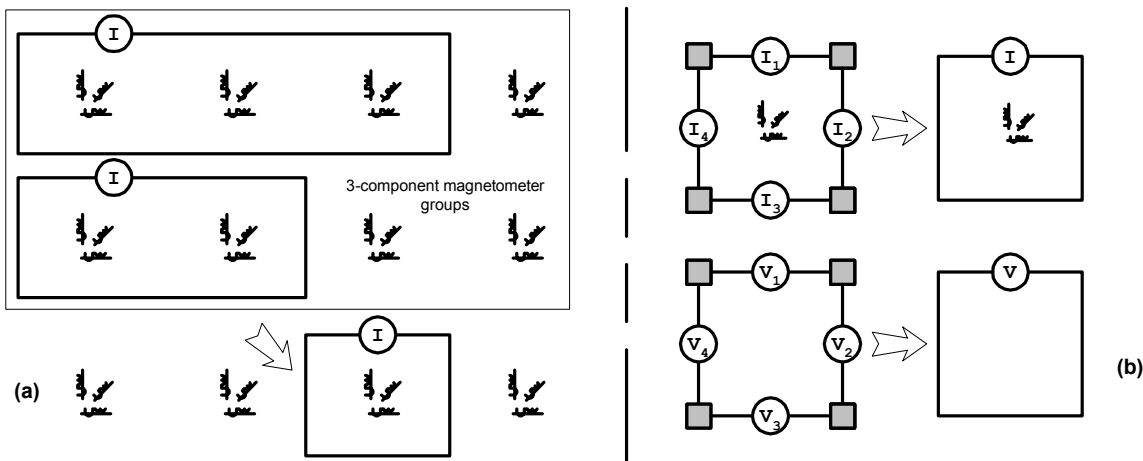


Figure 4. Superposition in controlled source EM or mixed grounded line/EM operations; (a) Transform data employing convenient but unusual excitations to standard moving loop results. (b) Transform grounded line measurements with shared electrodes forming closed loops to pure inductive sources or sensors.

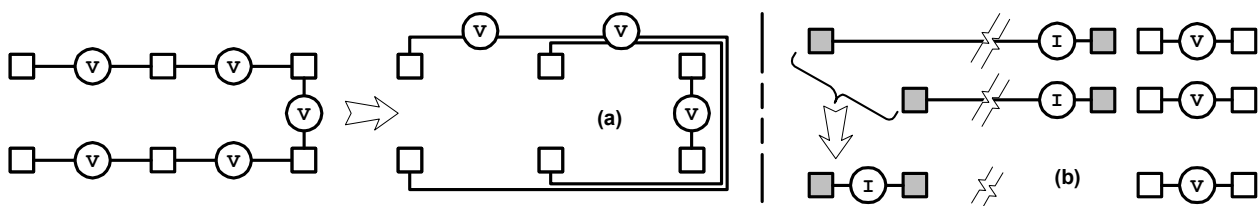


Figure 5. (a) Cross-line potentials calculated using simultaneously acquired data from parallel lines and one cross-line dipole; (b) This transformation requires extraordinary gain and phase accuracy as well as a current measurement resolved with at least the same accuracy and precision as all other measurements.