Fidelity of High-Impedance Electric Field Preamplifiers Compared with Normal Unbuffered Measurements in a Field Test

In the magnetotelluric (MT) method, we estimate the electrical resistivity of the Earth's crust and upper mantle using naturally occuring electromagnetic (EM) fields as sources (Vozoff, 1991). These sources are assumed to be planar in geometry and to propagate vertically into the Earth. From five channels of EM time series (2 orthogonal E-fields and 3 H-fields), the tensor impedance of the Earth is estimated over the typical range of 100-1000 Hz to 500 s period or longer. Models of resistivity from the impedance constitute a proxy for geochemical/structural history and present state in the Earth (Chave and Jones, 2012; Wannamaker et al., 2017).

While acquiring good-quality MT data on land in temperate climates is fairly well understood, collection over thick polar ice remained a challenge until the problem of very high contact impedance of the ice (up to 2 M-ohm at South Pole) in the E-field measurement was overcome. We designed custom buffer amplifiers with high input impedance to be placed at each contacting electrode within the firn (except for system ground) to transform the measurement to one of low impedance along the length of the bipole return to the receiver (Figure 1a). This avoids serious RC-circuit effects from combining untreated high contact and the capacitance between bipole and surface, which can cause erroneous rolloff distortion of the impedance soundings especially toward the higher frequencies. Details of the preamplifier design for Central West Antarctica and South Pole are in Wannamaker et al. (2004).

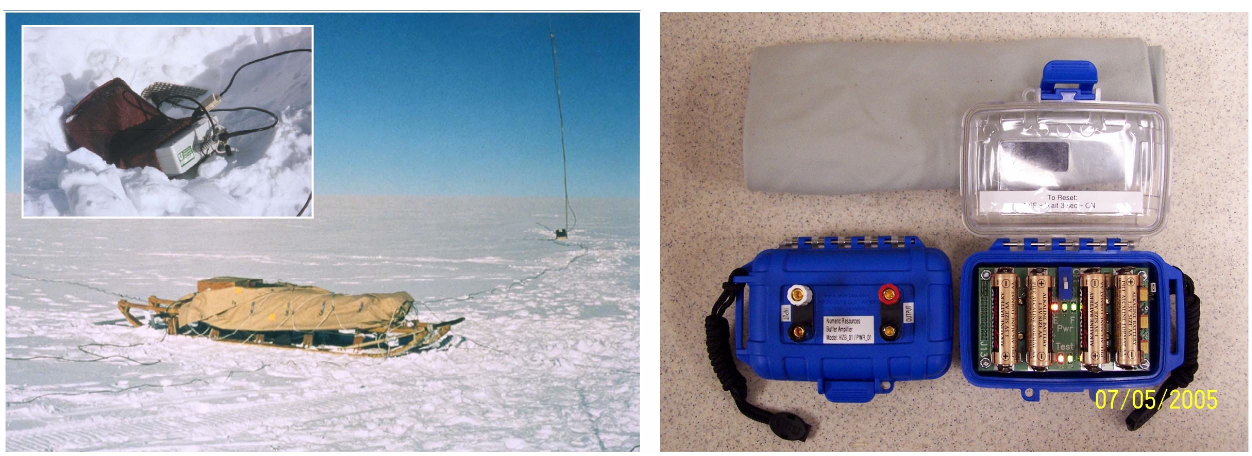

Figure 1. Left (a): MT instrumentation as was deployed at South Pole area. Nansen sled carries central recording module and batteries, towed by snowmobile. Digital radio antenna visible to right and various electric and magnetic field signal cables run in several directions. Inset shows high impedance electrode preamp attached to vertically installed titanium metal electrode, just before final burial. Right (b): Picture of current compact, simplified electrode preamp in "on" setting. These provide good data to 5 M-ohm contact, require only shielded twisted pair return wire, and can be interfaced to either + or L array receivers.

For field measurements in the Central Transantarctic Mountains project, we implemented a new design not requiring external digital control to allow interfacing with commercial MT receivers (right side of Figure 1). Power typically is supplied by 4 AA lithium-iron disulphide batteries internal, although external batteries or power sent along a wire in the bipole can be accommodated. Analog signals from each preamp are transmitted single-ended to the central MT recorder and input to the respective channel whether in +-array or L-array mode. Ground for each preamp is attached to system ground of the central recorder.

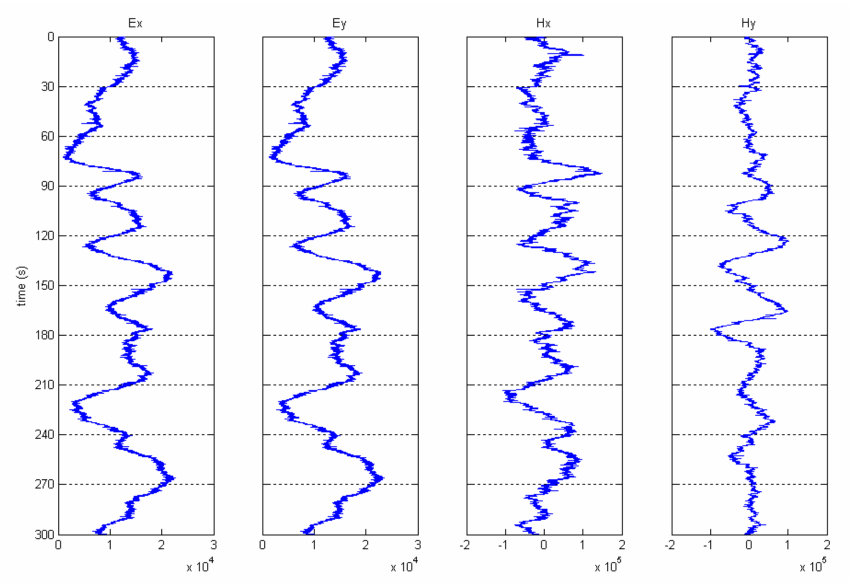

Figure 2. Electric field signals from high impedance electrode preamps of our design with 1 M-ohm series resistors in line (Ex-channel, left) compared to signals from normal E-bipole operation with lines connected directly to buried electrode (Ey-channel, right). Orthogonal magnetic channels shown for reference on the right.

A test of the current preamplifiers attached to a Phoenix V-2000 MT receiver of the New Zealand GNS Science organization was carried out in December 2006 during the course of a project across the Marlborough strike slip zone (Wannamaker et al., 2009). These included a parallel E-bipole test where one leg (y-channel) was a normal low impedance measurement using a single conductor bipole, while the other (x-channel) had a high-Z preamp placed in front of the electrode with a 1 M-ohm simulating resistor placed between preamp and electrode. Plots of the E-H traces over a 5 minute recording are shown in Figure 2. The two E traces appear indistinguishable, attesting to preamp fidelity. In a second test (Figure 3), 1 M-ohm resistors and preamps were placed at all electrodes and a full sounding taken to compare with a sounding measured the previous day with the normal low impedance configuration. These two soundings, processed using the robust remote-reference code accompanying the Phoenix receiver, also are very close demonstrating preamplifier quality.

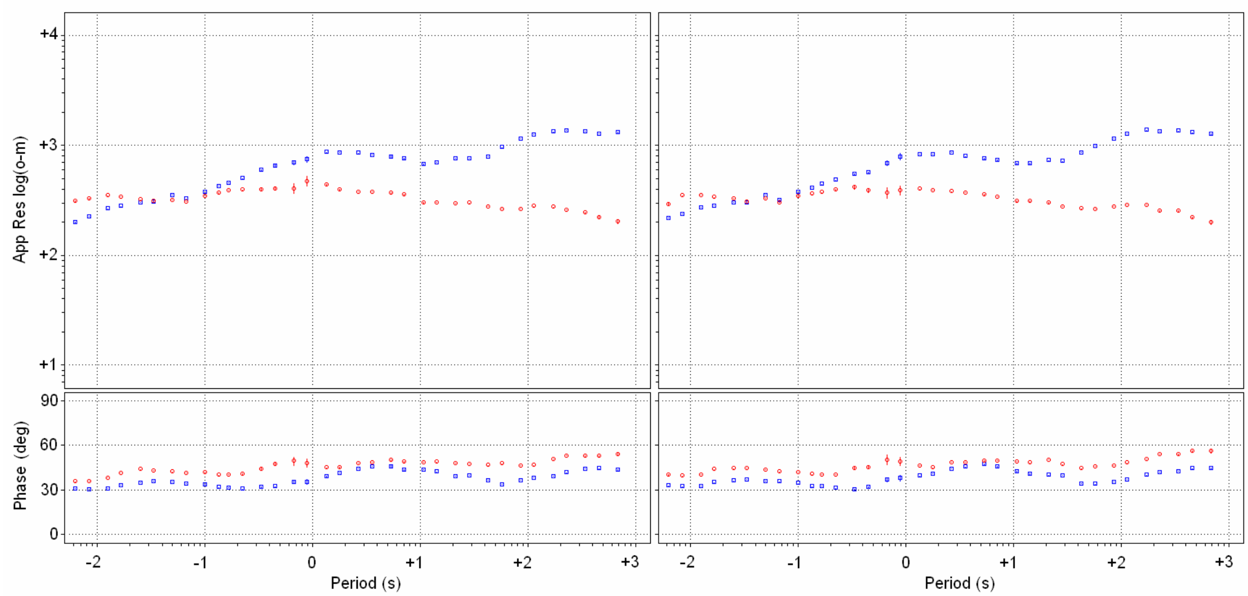

Figure 3. MT soundings taken under normal contact conditions (~1 K-ohm) (left), and with contact impedance raised through insertion of 1 M-ohm resistors between preamps and electrodes (right). Blue symbols are yx while red symbols are xy for x = N22E.

References

Chave, A. D. & A. G. Jones (eds) 2012. *The Magnetotelluric Method: Theory and Practice*. Cambridge University Press, 552 pp.

Wannamaker, P. E., J. A. Stodt, L. Pellerin, S. L. Olsen & D. B. Hall 2004. Structure and thermal regime beneath South Pole region, East Antarctica, from magnetotelluric measurements. *Geophysical Journal International*, **157**, 36-54.

Wannamaker, P. E., T. G. Caldwell, G. R. Jiracek, V. Maris, G. J. Hill, Y. Ogawa, H. M. Bibby, S. L. Bennie & W. Heise 2009. Fluid and deformation regime of an advancing subduction system at Marlborough, New Zealand. *Nature*, doi:10.1038/nature08204, 733-736.

Wannamaker, P. E., G. J. Hill, J. A. Stodt, V. Maris, Y. Ogawa, K. Selway, G. Boren, E. Bertrand, D. Uhlmann, B. Ayling, A. M. Green & D. Feucht 2017. Uplift of the Central Transantarctic Mountains. *Nature Communications*, 11 pp., doi: 10.1038/s41467-017-01577-2