IP and SIP – the practical link?

M. Ingham(1), S. Joseph(1), K. Ilse(2) and G. Gouws(1)

(1) *Victoria University of Wellington, New Zealand,*
(2) *Martin Luther University of Halle-Wittenberg, Germany*

Laboratory measurements on both consolidated and unconsolidated samples suggest that spectral induced polarization (SIP) measurements have the potential to provide a proxy for hydraulic conductivity. Nonetheless there are several difficulties related to developing SIP as an effective field technique. These relate not only to the inductive and capacitive problems associated with using an alternating current when extensive cabling is laid on the surface of the electrically conductive Earth, but also to the time required to obtain accurate measurements at low frequencies. In contrast to SIP, induced polarization (IP) measurements are not as prone to the same problems. In theory, the square wave current used by an IP measurement can be represented as an infinite Fourier Series of sinusoidal waves of increasing frequency. This means in principle that if the full IP signal is able to be recorded at a sufficiently fast rate, the SIP response of the ground should be able to be derived from it.

The relationship between IP and SIP responses, and the limitations in obtaining the SIP spectrum from the IP response, have been explored in four stages.

(1) By representing a measured IP voltage decay in terms of a mathematical function, such as a Debye relaxation, for which the Fourier Transform can be analytically calculated.
(2) By creating a synthetic time series of such an IP decay and numerically calculating the resulting Fourier Transform.
(3) By experimentally measuring both IP and SIP responses on laboratory samples and demonstrating that they related by Fourier Transformation.
(4) Trial field measurements using a purpose built instrument capable of measuring both the SIP and IP response.

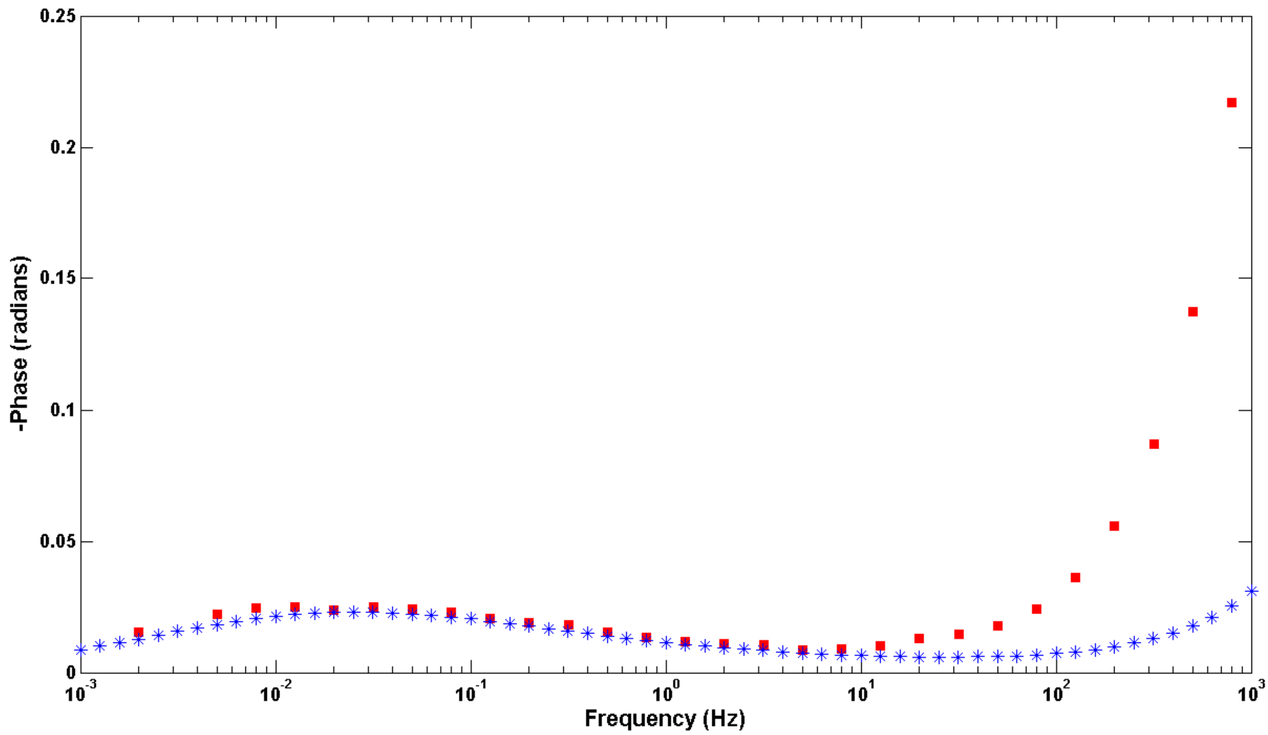

Fig. 1: SIP response of an unconsolidated sand sample measured in the laboratory. Blue stars – measured SIP response; red squares – SIP response calculated from the FFT of an IP measurement with pulse length 120 s.

The results of analytic calculations suggest that as long as the ratio of the IP pulse to the relaxation time of the principal relaxation is larger than about 5-10, the calculated Fourier Transform of the IP signal shows a perfect match to the SIP response. As this ratio decreases the frequency response is less well reproduced. When a synthetic time series is used as a basis for numerical calculation of the FFT, it is apparent that, in addition to the pulse length and the relaxation time, the overall length of the signal and the sampling frequency are important. This is further borne out by laboratory measurements on real samples. Such measurements also introduce measurement noise and demonstrate the need for suitable band averaging of frequency estimates calculated from the Fourier Transform. The quality of the calculated SIP spectrum can also be improved either by stacking of multiple measurements or by smoothing of the measured response. The efficacy of the second technique is illustrated in Fig. 1 which compares the laboratory SIP responses of an unconsolidated sand sample measured both directly and calculated from the FFT of a smoothed IP response using a 120 s pulse. The comparison between the measured and calculated responses in the region of interest at frequencies lower than 10 Hz is excellent.

The benefit of being able to derive an SIP spectrum from a measured IP signal is likely to be greatest for field measurements aimed at imaging the SIP response of the subsurface over both substantial depth and lateral ranges. Whereas a direct measurement of a single SIP spectrum over the frequency range 0.001-1000 Hz will take upwards of 25 minutes, depending on the number of individual frequencies that measurements are made at, the use of an IP pulse of 120 s pulse length will reduce the required time by at least a factor of 6. Adaptation of current commercial instrumentation is also possible meaning that new equipment is not required.