

## **Using Phase Sequencing and Marine Vibrators for Residual Shot Noise Removal and Simultaneous-Source Separation**

**Robert Laws<sup>1</sup>, David Halliday<sup>1</sup>, Ali Özbek<sup>1</sup>, and Jon Fredrik Hopperstad<sup>1</sup>**

<sup>1</sup>Schlumberger, Cambridge, CAMBS, United Kingdom.

### **ABSTRACT**

Compared with a conventional airgun source, a marine seismic vibrator allows much greater control of the emitted seismic wavefield. The phase, amplitude, and frequency spectrum of the emitted wavefield can all be controlled. In particular, we can choose to make the phase vary from one shot to the next in a carefully defined sequence. This ‘phase sequencing’ can be used to shift energy about in the frequency-wavenumber space in the common-receiver domain. In a marine seismic survey, the speed of wave propagation along the cable is bounded by the speed of sound in water. This limits the region in the frequency-wavenumber domain where seismic signal can occur and it therefore leaves an ‘empty quarter’ where there is no signal energy. By using phase sequencing we can exploit this empty quarter. One application of phase sequencing is to remove residual shot noise (the reverberant sound left over from previous shots) by moving it into the empty quarter. At its most basic, this can be done by using a ‘sine-cosine’ phase sequence: a 90° phase shift is applied to alternate shots. After deconvolving each shot by its corresponding phase we find that the noise (but not the signal) has been shifted into the empty quarter from where it can be removed by simple frequency-wavenumber filtering. The signal is not affected. Removal of the residual shot noise allows a reduction of the shot-time interval, which enables either denser shot sampling or faster acquisition. Another application of phase sequencing is in simultaneous-source acquisition and separation. In the basic case of two simultaneous sources, the crosstalk can be moved into the empty quarter by having the phase of one source change by 180° from shot to shot. More elaborate phase sequences can be used to acquire high-multiplicity simultaneous-source data. This can be done in a way that makes the data appear similar to spatially aliased data from a single source – a situation that is well understood and for which solutions have been developed. For the case of a high-multiplicity of sources, the empty quarter becomes very crowded, but advanced wavefield reconstruction techniques can be used to separate the data, giving the potential for high-multiplicity simultaneous-source acquisition with limited crosstalk. Phase sequencing cannot be directly used with airguns because we have almost no control of the phase of the airgun signal; control is limited to simple changes of amplitude and overall time delay.