# Joint designature of Tuned Pulse Source and Airgun data

## Introduction

The need for low frequency seismic data is now well recognized (ten Kroode et al, 2013). This need is coming from imaging targets under complex overburden such as basalt (Ziolkowski et al, 2003) and salt, from the ability of low frequency signal to mitigate the challenge of local minima in Full Waveform Inversion (FWI), the ability to improve resolution by reducing the interference of side lobes, and by the need for low frequencies for building blocky reservoir models. To acquire low frequency signal, we need sources that produce low frequency waves and receivers that record them. While great progress has been done with receivers such as ocean bottom nodes (OBN), micro-electromechanical systems (MEMS), solid streamers, and multi-sensor streamers, low frequency sources are only now becoming available. One such low frequency source is the Tuned Pulse Source (TPS) (Tellier et al, 2021).

The question that this paper answers is not whether TPS is better than Airguns. The question is what is the added value of adding TPS on surveys in which Airguns are already in the plan. To answer this question, we have to compare the results of processing Airgun data alone not to processing TPS data alone but to the results of processing Airgun and TPS data together.

One of the first steps in data processing is designature. Both Airguns and TPS are pneumatic sources and as such they produce oscillating bubbles. The designature process turns the bubble from noise to signal. In this paper we present a method of joint designature as an alternative to the method of separate designature of each source.

## Method

The acquisition method followed the Dispersed Source Array (DSA) concept (Berkhout, 2012). The processing method is using joint designature as described below.

Seismic data are convolutions of the source and receiver signature-wavelets and the earth's reflectivity. In this section of this paper we focus on the sources and leave out deghosting and receiver designature.

$$Data = Signature_Wavelet * Earth_Reflectivity$$

In the frequency domain, convolution is multiplication and we can write

$$D = W \cdot M$$

Where D is the data, W is the signature wavelet and M is the unknown reflectivity. The solution is

$$M = \frac{W^* \cdot D}{(W^* \cdot W \ + \ PWF)}$$

$W^*$ is the complex conjugate of $W$ so $W^*W$ is $|W|^2$. $PWF$ is the pre-whitening-factor which is needed to avoid a division by zero because for some frequencies the spectrum of $W$ is very small. $PWF$ may be frequency dependent. Although the above is written in the frequency domain it can be written in the time domain, in which case $M$ and $D$ become vectors, $W$ becomes a matrix, and $W^*W$ becomes a Toeplitz matrix. So far, we follow Robinson and Treitel (1980). This paper is about joint deterministic designature so for now we assume that we know the wavelet $W$ and we do not need to assume that $M$ is white and $W$ is minimum phase wavelet.

Airgun data are $D_{AG} = W_{AG} \cdot M$ , and the TPS data are $D_{TPS} = W_{TPS} \cdot M$. Instead of processing TPS and Airgun data separately, we follow Claerbout (1992) and write it as an inversion,

$$\begin{bmatrix} D_{AG} \\ D_{TPS} \end{bmatrix} = \begin{bmatrix} W_{AG} \\ W_{TPS} \end{bmatrix} M$$

with two equations with one unknown. The solution is

$$M = \frac{W^*_{AG} \cdot D_{AG} + W^*_{TPS} \cdot D_{TPS}}{|W_{AG}|^2 + |W_{TPS}|^2 + PWF}$$

**Data Example**

The TPS was tested during surveys in which the production source was a conventional array of airguns. The TPS was had a firing chamber of 26500 cui at 1000 psi and the Airgun array had a total volume of 5110 cui at 2000 psi. The TPS did not replace the Airguns but was tested as an additional source. Some of the data are shown in Figures 1 and 2.

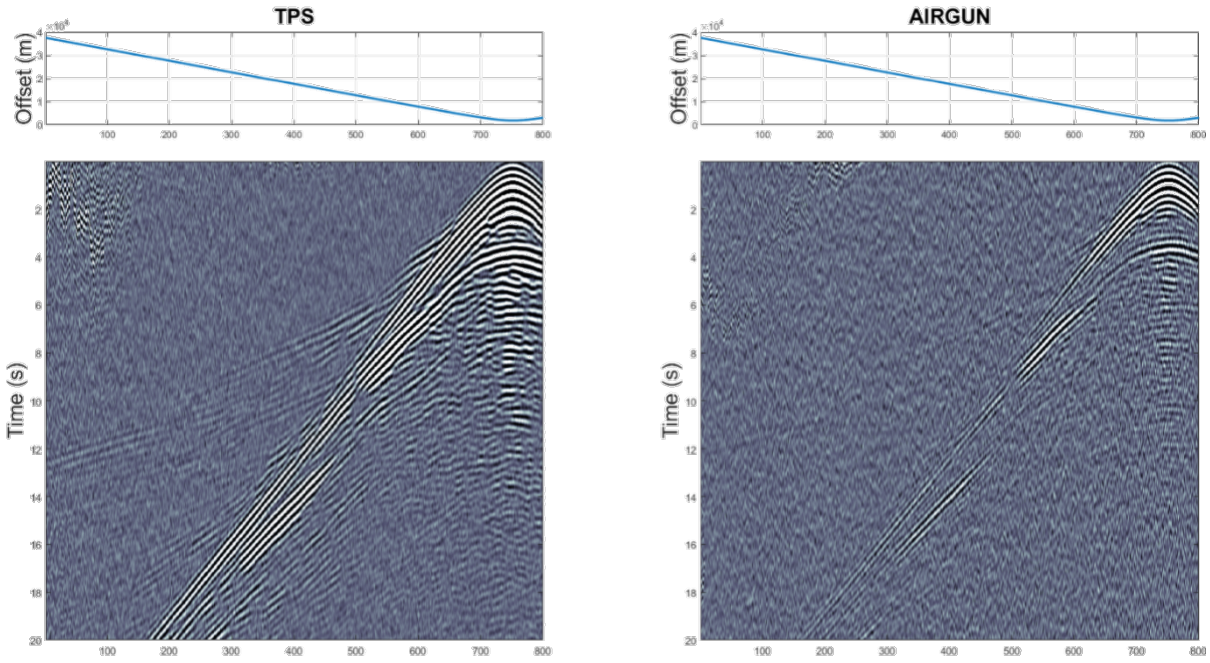


***Figure 1:*** *Low frequency content (3Hz and below) in common receiver gathers. 5110 cui Airgun array on the right and 26500 cui TPS on the left. Note the refractions up to 40 km offset.*

The data are in processing. So far, we have produced the spectra of the joint designature and compare it to separate designatures in Figure 3.

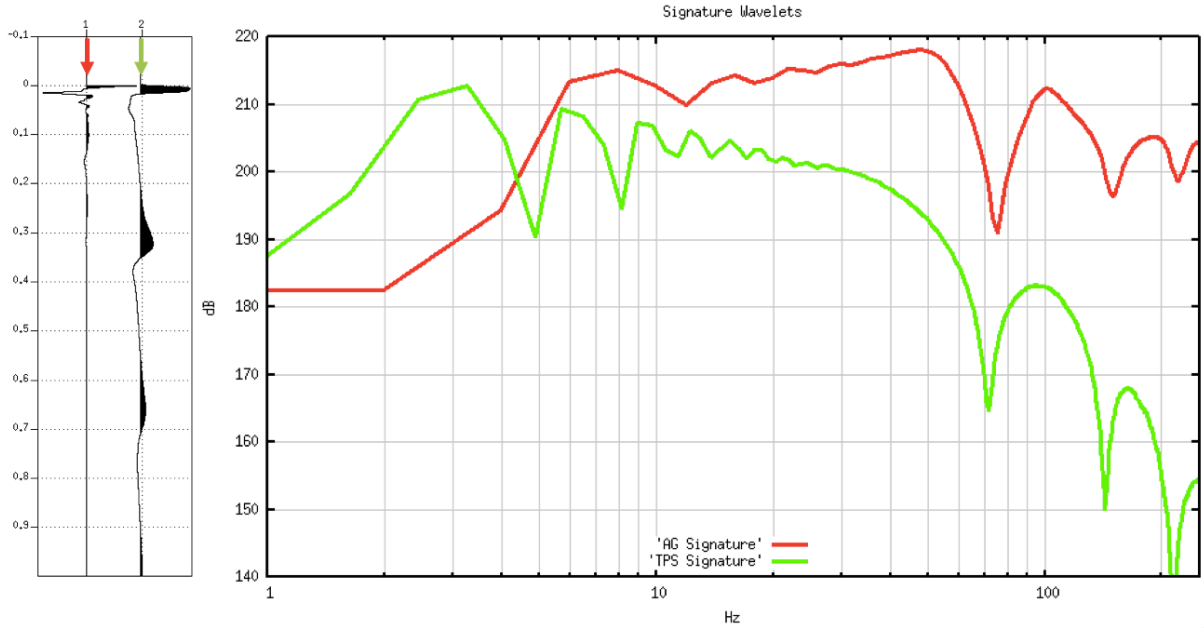


***Figure 2:*** *Spectra of a 5110 cui Airgun array in green and a single 26500 cui TPS in red. The two sources are by and large complementary. TPS provided much stronger signal up to 4.5 Hz. Airguns provide signal much better signal above 30 Hz. Note the diversity in the bubble peaks and troughs. The two sources were both deployed at the same depth so there was no diversity in the ghost notches.*

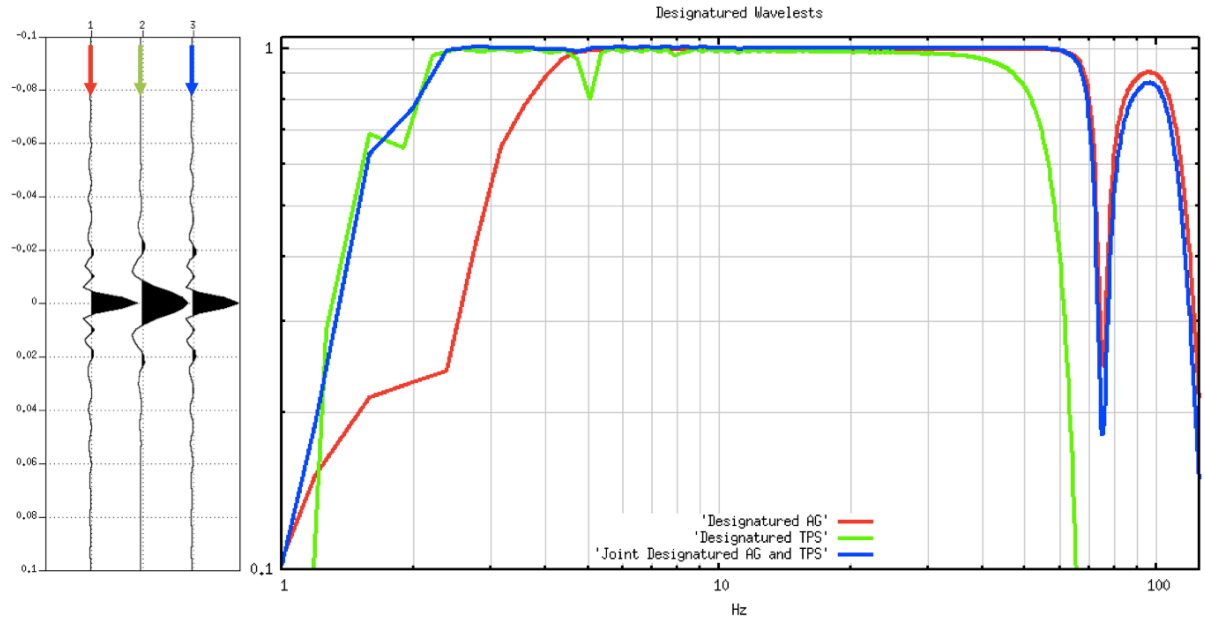


***Figure 3:*** *Spectra after designature. Note that there are three traces here. In addition to the green and red TPS and Airguns designatured separately, there is a blue spectrum of the joint designature. The joint designature takes advantage of the diversity in the bubble peaks and troughs.*

## Environmental impact

The TPS is stronger than Airguns only below 4.5 Hz. The hearing threshold of the largest whales is believed to be at about 7 Hz. The TPS is 12 dB weaker than the Airguns at 20 Hz, 30 dB weaker at 50 Hz. 50 dB weaker at 200 Hz.

## Discussion

For TPS to be considered as a replacement to Airguns, it has to be deployed with a mixture of large and small volumes of firing chambers. Given the abundant availability Airguns it is more practical to deploy TPS as an additional source and not as a replacement to Airguns. Whether a mix of large and small volume TPS is used of large TPS is deployed as an additional source to conventional Airguns, the question is whether to mix large-volumes low-frequency sources and small-volume high-frequency sources in a conventional array or whether to use Distributed Sources Arrays (DSA). Relaxing the need for TPS and Airguns to be spatially collocated, DSA have the advantage of using volume-dependent spatial-sampling to optimize compressor and also the opportunity of using volume-dependent source depth to achieve ghost notch diversity and broader band. In this paper we follow the DSA idea and form the array in processing using joint designature.

Different signatures, or voices, of different sources in a DSA, provide an opportunity to use voice recognition in deblending.

Deterministic designature implies good knowledge of the signatures. In this paper we are not covering the methods of recording the signatures which are a combination of near field hydrophones, high-quality ocean bottom nodes that enable up/down separation, and supported by numerical source modelling.

## Conclusions

TPS and an array of conventional Airguns are complementary with good diversity in bubble peaks and troughs. Jointly they can provide broad band signal. Joint designature of data from the different source takes advantage of the diversity in the sources spectra to produce broad band spectra.

## Acknowledgements

People who contributed but are not named as co authors : …

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