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# Optimal Seismic Wave Field Sampling: A Wave Number Approach to Acquisition Fundamentals

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## Summary

The traditional approaches to acquisition design focus on coherent noise reduction with the use of source and receiver arrays. These are not perfect since they also filter signal. Traditional processing has a dual role, eliminate the residual noise and repair the signal. It is too late; the damage is already done with the data, both signal and noise, complicated by array filtering and aliasing.

In 1987 Nigel Anstey advocated designing on the signal and was followed by Ongkiehong (1988) who demonstrated that controlled spatial aliasing of the noise resulted in improved signal to noise ratio in f-k space.

These improvements were limited to the 2D data world and became redundant with the surge of 3D seismic activity.

In 1998 Vermeer established the same design advantages in acquisition and processing with 3D data; however since then the methodology has not been universally recognized.

These early innovations require re-examination.

## Theory / Method / Workflow

In acquisition we are concerned about both vertical and horizontal resolution. Vertical (temporal) resolution is a function of signal bandwidth where horizontal (spatial) resolution is determined by receiver spacing, effectively the Group Interval.

Since we sample the seismic wave field, we filter it and run the risk of inadequate sampling which will cause aliasing. To properly understand acquisition and arrays we must understand aliasing. Temporal aliasing is restricted to a large extent by the anti-alias recording filter. Spatial aliasing is epidemic in seismic data. Since noise has a shorter wavelength than signal it is more likely to be spatially aliased than signal.

Aliasing is readily identified on seismic records by the “checkerboard” effect. This is a consequence of inadequate sampling on a dip rate. However, statics, NMO and amplitude changes in the signal are spatial changes which manifest as spatial aliasing. These effects are not generally known but can be studied with models in f-k space. These models provide insight into aliasing as well as explaining traditional difficulties with f-k filtering. The dip rate or apparent velocity is the link between t-x space and f-k space.

The 2D Fourier Transform provides significant advantages in analyzing the distribution of signal and noise. The plane of temporal frequency (f) versus spatial frequency (k) is the 2D amplitude spectrum of the t-x section. So time-space (t-x) is the transform of frequency-wavenumber (f-k). Spatial aliasing has severe effects on the performance of multi-channel processes such as f-k filtering and the industry has had difficulty with this process. It should be emphasized that the filter is honourable but is compromised with the quality of the input data, specifically the presence of aliasing. For example, f-k filtering should be applied to SHOT gathers rather than CMP gathers since the CMP gathers can have twice the trace spacing which can cause aliasing.

**The 3D case:**
One distinct benefit of 2D acquisition sampling is that it can be recorded with equally spaced receiver intervals and the data can be readily investigated and filtered in f-k space if attributes such as aliasing, statics, NMO and amplitude changes are corrected. However even with equally spaced sampling along source and receiver lines in 3D acquisition there is no even sampling in all directions (azimuths) because of the wide spacing between lines. This limits the effectiveness of 3D f-k filters. This seemed to preclude the advantages of f-k filtering on 3D data gathers since uniform sampling in all directions is a prerequisite. This issue was resolved by Vermeer who showed that a clever sort of commonly acquired 3D data can provide the long awaited evenly distributed 3D gather. Three dimensional f-k filters can be effectively applied in this domain, the Cross-Spread Gather. Since it is theoretically impossible to properly sample the entire pre-stack wave field, the symmetrical sampling of the Cross-Spread Gather provides the next best alternative.

## Results, Observations, Conclusions

This presentation will link the fundamental and basic seismic theories in a daisy chain to establish that what is old and 2D based is not necessarily redundant even though it has largely been abandoned as inadequate. Beginning with 2D x-t space to illustrate the differences between signal and linear noise behavior it goes into array sampling and filtering and the transforms into f-k space. Aliasing is a major issue in this sequence and the benefit of the Shell/Ongkiehong approach to acquisition is explained in terms of signal preservation and deliberate linear noise aliasing in f-k space, resulting in noise removal and significant enhancement of the signal to noise ratio. This leads to a discussion of f-k space and f-k filtering in the context of 2D data. Traditional problems are identified and explained. With the surge of 3D activity these 2D solutions became redundant since equally spaced field sampling in all azimuths is impossible. Not only did the solutions become redundant they were eliminated.

Vermeer developed a methodology of symmetrically sampling the 3D wave field which created the opportunity to apply the Shell/Ongkiehong approach. This Cross-Spread Gather provides the opportunity to process the pre-conditioned 3D gathers through 3D f-k filters with the same benefits as the 2D case, namely signal preservation and linear noise attenuation.

The presentation will include real data examples of the effectiveness of these basic theories.

This is not intended to teach you something new. More a case of “let me look at that again”. The risk for me is that you are offended since this is too simple and basic. However, there is a perceived need to get back to the basics and consider the consequences of seismic acquisition and processing design on the data fidelity prior to interpretation.

## Acknowledgements

The essence of this paper is largely due to the insight of my late dear friend and colleague, Dr. Lawrence C. Wood. In over 45 years of our relationship he consistently pointed the way and without his unique understanding of the seismic process I would never have learned to "see" seismic the way I think I now can.

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