# The effect of geophones and geophone arrays on signal

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## Introduction

Recently various papers (e.g. Criss et al., 2005) have praised the qualities of Vectorseis and Vectorseis acquisition while emphasizing the bad properties of geophone arrays. In particular, remarks about array effects on signal amplitude, including azimuthal effects, pushed me into looking again at these effects and to see for myself how serious it is actually to use geophone arrays.

In Vermeer (1990), I spend pages 51 - 66 on discussing arrays (I called them patterns in that book), including a section on "Detrimental effect of patterns on signal". Figure 4.5 compares the pattern response with the ideal response that might be achievable in digital processing, and I remark that the usual field pattern response is very bad from a digital filter point of view. And in the final chapter it says: "The ultimate in 2-D single-component data acquisition is reached if, for a given desired maximum frequency, the basic sampling interval is used both for shots and receivers without the application of shot and receiver patterns". So, it is clearly not possible to call me a staunch supporter of field arrays. You may even wonder why my book is not more often referred to by the proponents of single-sensor acquisition.

My first book did not deal yet with 3D acquisition. That came with Vermeer (2002). This second book assumes the first book as known to the reader, but it includes chapter 1 with some of the highlights from the first book. At the time of writing the second book, 3D surveys were acquired in general with much larger sampling intervals than customary in 2D, hence arrays are needed to suppress noise and the arrays will at the same time hurt the signal. My book gives recipes for better sampling, but it still assumes the use of arrays and not much text is spent on single-sensor acquisition. An important remark is: "Although single-sensor recording is becoming technologically feasible, using 20- or 25-m station spacings with correspondingly shorter field arrays would already provide a great improvement over current practice". And this is still my current view: WesternGeco with its single-sensor Q-Land system is providing an enormous step forward in sampling, but it has not been shown yet that it is really the way to go, and the benefits of sampling at (what I call ) the basic signal sampling interval have not been fully investigated. Therefore, sampling at the basic sampling interval or at the adequate sampling interval (Baeten, 2000) is perhaps overkill. Of course, this does not apply to sampling intervals advocated by various authors, who do not want to change the sampling interval from the conventional values to smaller values. I have my doubts and I would suggest that also VectorSeis data would benefit a great deal from at least using the basic signal sampling interval (although I am not convinced yet that that will be small enough under all circumstances; but that is another discussion).

## Effect of arrays on signal

After this long introduction, I would like to focus now on the effect of field arrays on signal. I have computed the 2D array response for a 12-element linear array for various values of $f\,\Delta r\,/\,V_{int}$, where $f$ is frequency, $\Delta r$ is array length (or station interval for that matter), and $V_{int}$ is interval velocity by replacing (apparent) wavenumber $k$ by $f \sin i\,/V_{int}$, where $i$ is the reflection angle. The result is shown in Figure 1. If the station interval is chosen according to the formula $\Delta r = V_{int}\,/\,(2\,f_{max} \sin\theta)$, and the angle $\theta$ is chosen to be 30° (that is what I recommend for small dips; for larger dips $\theta$ has to be enlarged accordingly), then $f\,\Delta r\,/\,V_{int} = 1$. The corresponding curve shows that the maximum frequency would be suppressed nearly 12 dB for a reflection angle of 50°. The dominant frequency, if taken to be $f_{max}\,/\,2$, would be suppressed less than 3 dB at 50°. This shows that for this choice of station interval the array effect is relatively small, although not negligible. I would say that for AVO analysis up to 30° the effect is negligible.

However, station intervals are often chosen much larger than according to the above formula; especially for small dips $\theta$ tends to be chosen smaller than 30°. Even a 50% larger station interval ($f\,\Delta r\,/\,V_{int} = 1.5$) produces a dramatic loss of high frequencies. This analysis has made me more aware of the dangerous effect arrays may have on signal amplitude. It strongly underlines the necessity of choosing smaller than usual station intervals. However, if the station spacing is selected smaller than the sampling interval required for alias-free sampling of the prestack data, then the effect of the array on signal is negligible.

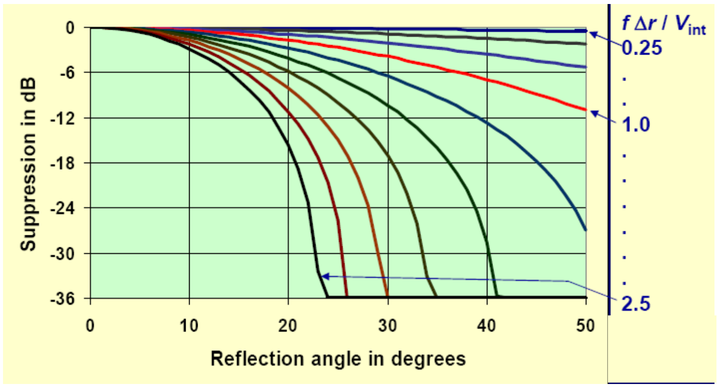


Fig. 1. Effect of linear array on signal in 2D as function of reflection angle and constant $f\,\Delta r / V_{\mathrm{int}}$ ($f$ is frequency, $\Delta r$ is array length, $V_{\mathrm{int}}$ is interval velocity).

## Azimuthal effect

Figure 1 describes the suppression of high frequencies by the array effect for the 2D situation. For 3D the effect of the source array has to be taken into account as well. Various I/O authors point out that the azimuthal effect of arrays is another effect that one wants to avoid, especially in 3D acquisition. It is my impression that the azimuthal effect as thought of by these authors does not include the effect of the source array, but only the effect of a linear receiver array. In that case the azimuthal effect is obvious: the suppression of high frequencies is maximal for energy traveling in the inline direction, whereas there is no suppression for energy traveling in the crossline direction. However, if a receiver array is needed to suppress coherent noise, a source array is needed just as much. (Single deep holes are often used to prevent the generation of ground roll; if this is not sufficiently successful, a receiver array may be needed for ground-roll suppression. A source array is not quite feasible with deep holes; therefore it would be necessary to use *areal* receiver arrays. The design of such arrays should be such as to minimize the azimuthal effect: circular arrays would be best, see Chapter 3 of Vermeer, 2002.) A linear source array can be composed easily with vibrators and of course also with shallow dynamite sources.

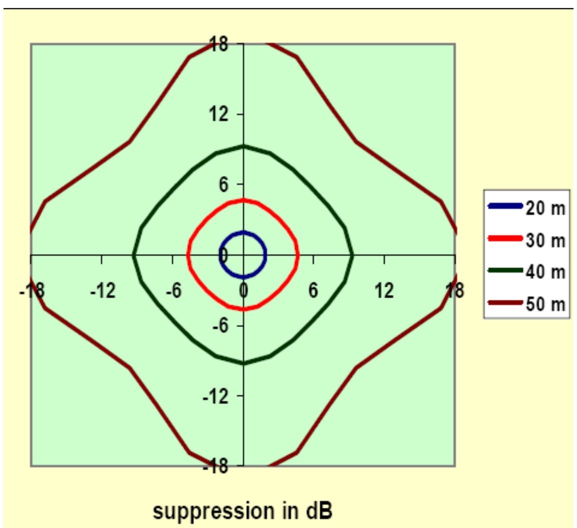


Fig. 2. Effect of linear source array and linear receiver array on signal as a function of azimuth in 3D for array lengths 20, 30, 40, and 50 m. The graph was made for $f$ = 70 Hz, $V_{\mathrm{int}}$ = 2500 m/s, and reflection angle = 40°.

If both linear receiver and linear source arrays are used, the combined effect can be computed using the product of the individual array responses, as a function of $k_x$ and $k_y$. Assuming that the source array has the same response as the receiver array, Figure 2 has been computed to illustrate the azimuthal effect of the two arrays. It shows that as long as the apparent wavenumber stays well inside the pass band of the two-dimensional array (suppression less than 6 dB), the response does not vary much with azimuth. The azimuthal effect becomes serious only when the signal suppression is already significant. This means that the loss of high frequencies and the consequential effect on signal amplitude is more serious than the azimuthal variation of the signal.

## Signal emergence not vertical

Another aspect of sampling with conventional geophones instead of with 3C sensors is the effect of the deviation of the angle of emergence from vertical. (Tilt compounds the problem, and may be corrected for using VectorSeis). It is a well-known effect, but for completeness' sake I made another graph (Figure 3) demonstrating the effect as a function of reflection angle and the ratio between the surface velocity $V_{\mathrm{shallow}}$ and the interval velocity $V_{\mathrm{int}}$. The figure demonstrates that the effect can become quite serious for high velocities at the surface, whereas it is negligible in areas with low weathering velocities. Figure 4 illustrates the effect for an actual interval velocity distribution. The time-variant nature of the effect calls for a time- and offset-variant angle-of-emergence correction, especially in the more serious cases. This correction would be necessary for a more accurate AVO analysis.

(Alex Calvert (GXT) pointed out to me that the above discussion does not take into account that the geophones measure the total wavefield, upcoming plus downgoing (reflected and converted waves). Any corrections for deviation from vertical have to take this effect into account.)

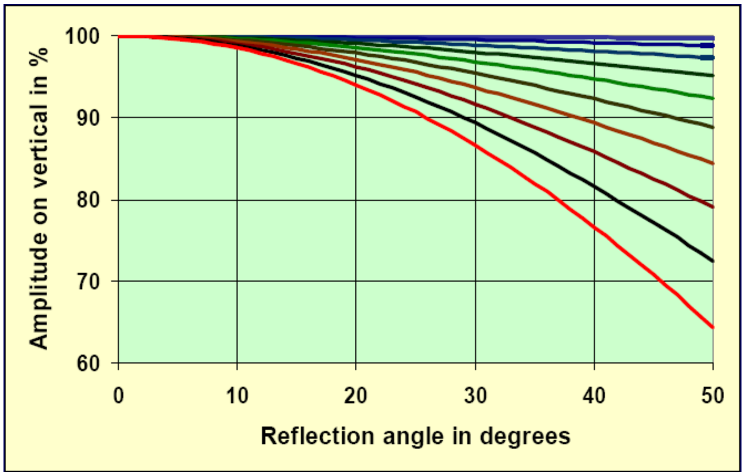


Fig. 3. Amplitude on vertical component in % for various values of $V_{shallow}$ / $V_{int}$. The ratio $V_{shallow}$ / $V_{int}$ varies from 1.0 (red curve) to 0.1 (nearly horizontal curve) in steps of 0.1.

## Conclusions

When comparing the virtues of 3C recording (with MEMS sensors) with conventional recording with coil geophones and geophone arrays, it is necessary to make a careful comparison of all aspects involved. In this short note only the aspects of the effect of arrays on signal have been discussed and the effect of non-vertical emergence of the seismic wavefronts. This note shows that the effect of arrays on signal can become quite serious if the station intervals are not chosen in accordance with aliasing criteria. However, if the station intervals are chosen properly, the effect of arrays on signal is not very serious. Also the azimuthal effect of arrays on signal is not serious in the case of adequate station intervals. Note that these adequate station intervals are needed anyway for optimal processing, in particular optimal imaging. The loss of energy due to non-vertical angles of emerging rays is negligible in most situations. Only in case of high velocities at the recording surface, can the effect become serious and will 3C recording have a definite advantage.

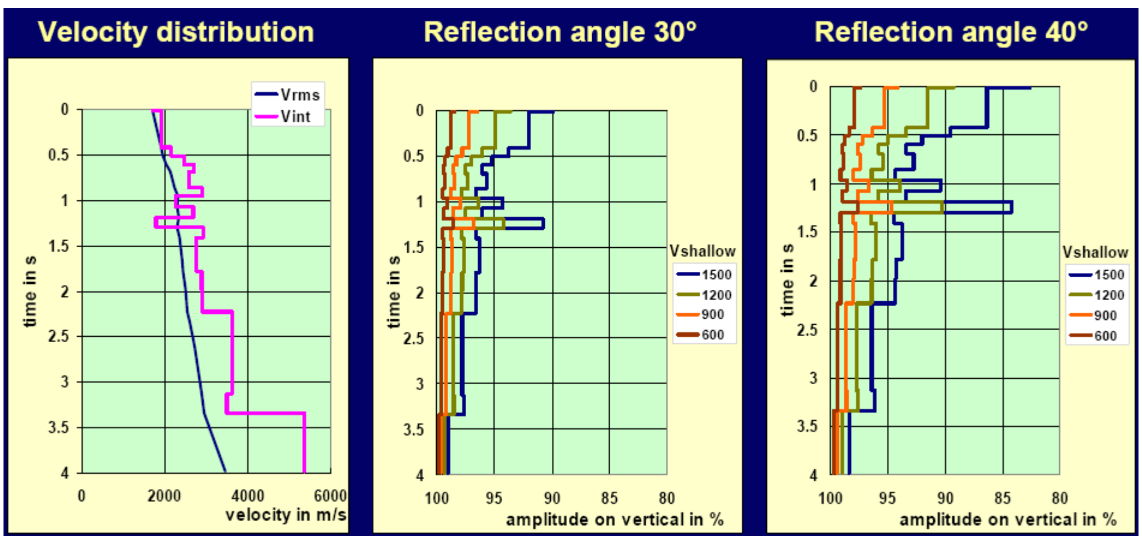


Fig. 4. Effect of non-vertical arrivals for various velocities in shallow layer.

## References


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