# Fold, Fresnel zones and imaging

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## Abstract

Fold can be defined in two different ways. One way is to count the number of traces in each bin (point count); another way is to count the number of overlapping coverage areas (areal or continuous count). In 2D, a single shot produces continuous single-fold coverage along the line segment corresponding to the midpoint range. The number of overlapping line segments in anyone point along the surface determines the continuous 2D fold-of-coverage. In 3D, a single shot (or another basic subset, such as cross-spread or zigspread) produces continuous single-fold coverage across the area corresponding to the midpoint range. The number of overlapping midpoint areas in anyone point along the surface determines the continuous 3D fold-of-coverage. It only makes sense to discuss continuous fold in case the data have been properly sampled, i.e., allow the faithful reconstruction of the underlying continuous wavefield.

The concept of continuous fold-of-coverage can be extended to illumination fold, DMO-fold and imaging fold, which are all measures used in 3D survey design. Continuous fold leads to a better distinction between focusing/defocusing effects on one hand and shadow zones on the other hand. It also allows a logical choice of which data to include in common-image gathers and how many of those gathers should be constructed for optimal velocity analysis in prestack migration.

Fresnel zones are universally used in the industry as a measure of how far to extend the migration radius, whereas the better measure is the zone of influence, which is determined by the length of the seismic wavelet. The zone of influence must be included in 3D-survey design to define the migration fringe area.

## A discussion of "fold"

Fold, fold-of-coverage and multiplicity are all expressions for the same notion. Usually, fold is thought of as the number of traces sharing the same midpoint (in 2D acquisition), or the number of traces sharing the same bin (in 3D acquisition). Computing fold is counting traces. However, another definition is possible based on the recognition that proper spatial sampling (producing all those traces) allows for reconstruction of the underlying continuous wavefield. With proper sampling, it is appropriate and instructive to describe fold – at any surface position – as *the number of overlapping midpoint areas of the basic subsets of the chosen 3D acquisition geometry*. [*Basic subset*: collection of data with slowly varying spatial attributes, suitable for imaging, also called minimal data sets (Padhi and Holley, 1997). Examples are: cross-spreads, 3D shot gathers.] In other words: fold can also be considered as a continuous function of the midpoint coordinates of overlapping subsets. Computing fold is now counting overlapping midpoint areas. In the concept of continuous fold, fold is discontinuous at the edges of any (basic) subset, unless the subset is adjacent to another subset. Note, however, that this description of fold cannot be (directly) applied in geometries that are inherently spatially discontinuous, such as the multi-source multi-streamer configurations.

The idea of continuous fold is not new. It was already used to describe fold for 2D data, where it is known that each receiver-spread length produces single-fold coverage along a distance equal to half the spread length. If fold is counted correctly, there should be no difference between the continuous fold count and the discrete fold count. Disparities may arise if the binsize of a geometry is enlarged. In my view it is incorrect to call the ensuing increase of number of traces in each bin an increase in fold. Similarly, sub-binning to smaller bins (as possible with bin fractionation, Cordsen, 1993) does not lead to lower fold-of-coverage, though it may be called a reduction in stacking fold.

The concept of continuous fold-of-coverage can be extended to continuous illumination fold, image fold and DMO fold. Each (continuous) midpoint area corresponds to a continuous area on any reflector that has been illuminated (the area of specular points corresponding to the midpoint area). Illumination fold at any point is just the number of overlapping illuminated areas. This is illustrated in Figure 1, which shows the illumination areas for four adjacent cross-spreads for two situations. Each area that has been illuminated can be imaged, apart from incomplete images along the edges of illuminated areas. Therefore, the image fold is at best equal to the illumination fold. From each point of a single-fold area of illumination, a normal-incidence ray may be traced to the surface, giving rise to a surface area for which DMO images can be constructed. The DMO fold at any point corresponds to the number of such overlapping surface areas at that point. Because of edge effects the DMO fold is at best equal to illumination fold. (This discussion of continuous fold expands on a similar discussion in Vermeer, 1998.)

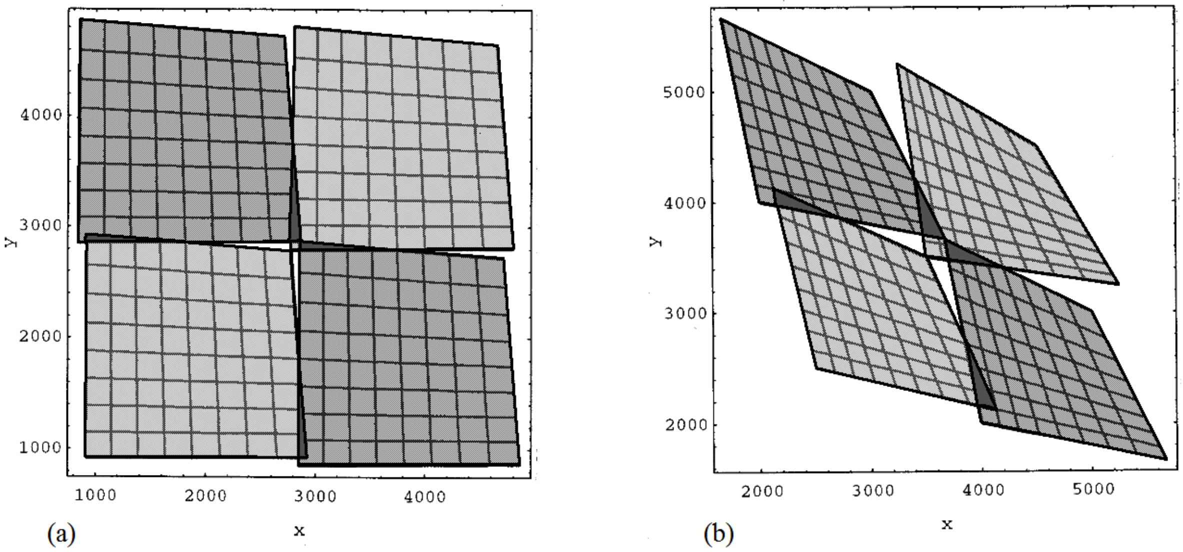

**Figure 1 Illumination of 15° (a) and 45° (b) dipping events by four adjacent cross-spreads.**

*Note that illumination fold can be considered a continuous function inside the cross-spread, whereas it is discontinuous across the edges of the cross-spreads. Although the corresponding midpoint areas are adjacent, the illumination areas overlap partially, and show gaps between them.*

## Applications of the concept of continuous fold

The concept of continuous fold can be usefully applied in the computation of illumination fold in 3D modeling programs. Rather than computing the raypaths for all shot-receiver pairs in the geometry, it is sufficient to compute the raypaths for the shots and receiver pairs that make up the edges of the basic subsets in the geometry. The corresponding reflection points for each basic subset define a closed polygon, each polygon increasing the fold count by one across the whole area of the polygon.

In exceptional cases the illumination area of a basic subset will not be a single area, but it may split into several disjoint areas because of focussing effects. In such cases refinements will be necessary.

An important consequence of the insight that image fold cannot be higher than illumination fold, which in turn will not be larger than fold-of-coverage (except at edges, see Figure 1), is that the number of traces in an image gather should not be larger than the nominal fold. If the number is larger, some of the image traces will show incomplete images, which may give rise to false analysis results. The input to each trace in an image gather should be carefully chosen to correspond to a single-fold subset of the total data set.

## Fresnel zones and zone of influence

Fresnel zones were originally defined only for monochromatic waves. Brühl et al. (1996) show that the idea of *first* Fresnel zones can be readily extended to broadband data. It is defined as the area around a specular point, which leads to maximum (reflected) energy. Brühl et al. discuss Fresnel zones only from a modeling point of view, but their discussion can be readily expanded to migration. In modeling, the energy of the reflected wavelet is measured as a function of the radius of the reflecting circular disk. In migration, the energy of the migrated reflection can be measured as a function of the migration radius. In both situations, the energy starts from zero for zero radius, then increases to some maximum value, and next oscillates until some stable energy level is reached. In both cases the first Fresnel zone corresponds to the radius which produces the maximum energy. For modeling, this is illustrated in Figure 2 (taken from Brühl et al., 1996).

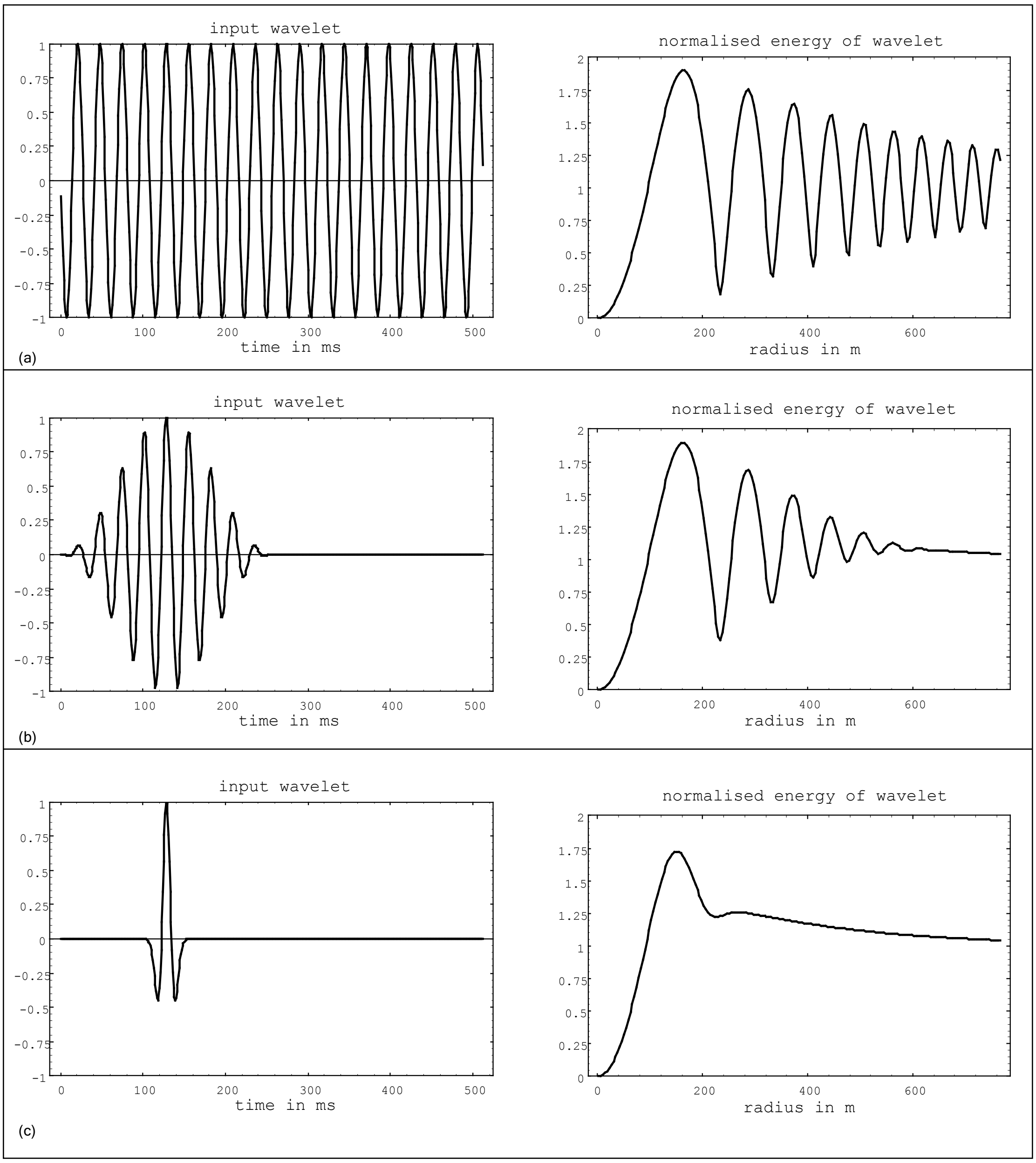

**Figure 2 Illustration of Fresnel zones for different wavelets. On the left the input wavelets are shown, all with central frequency of 37.1 Hz, on the right the energy as function of the radius of a circular reflector. The reflector depth is 1000 m, the velocity is 2000 m/s. The Fresnel zone is in all cases defined by the maximum of the energy function. (a) monochromatic wavelet, (b) narrowband wavelet, (c) broadband Ricker wavelet.**

The wavelet considered in Brühl et al. consists of a reflected wavelet from the circular disk itself, and a diffraction wavelet from the edge of the disk. Only if the radius of the disk is large enough, the two wavelets will be separated, as illustrated in Figure 3. The length of the wavelet and the difference in traveltime between specular point and disk edge determine when the two wavelets are fully separated. Brühl et al. define the zone of influence as:

*The zone of influence is the area on the reflector for which the difference between the reflection traveltimes* *and the diffraction traveltimes is less than the length $\Delta t$ of the wavelet.*

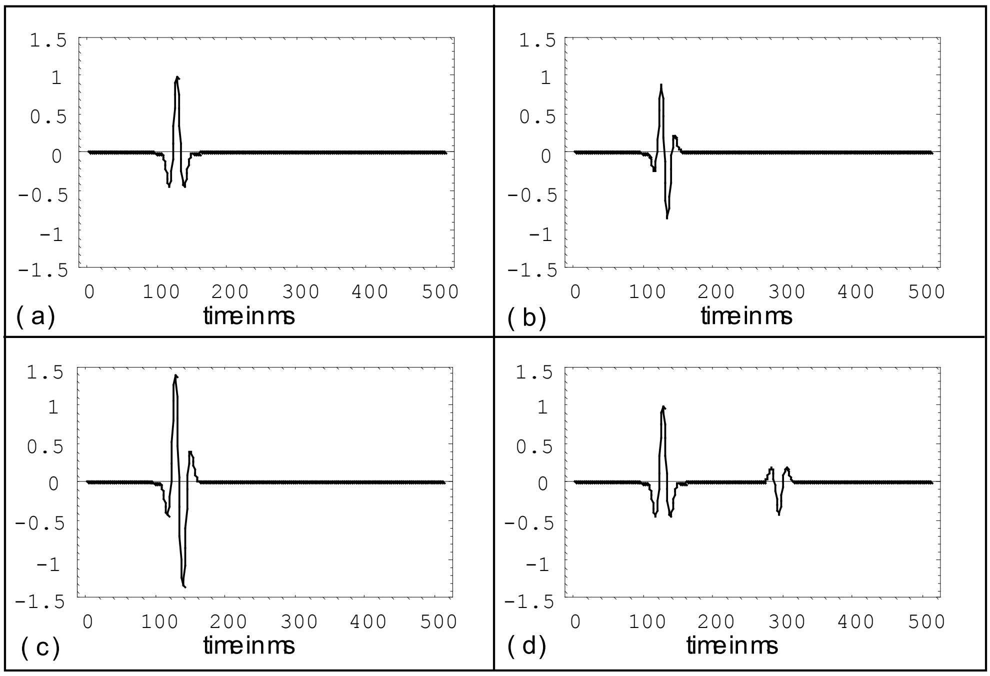

**Figure 3 The reflected wavelet as a function of the radius of a circular reflector. (a) input wavelet, (b) reflected wavelet for smallest radius for which normalized energy equals 1, i.e., radius corresponding to Brühl et al.'s generalization of Berkhout's definition of Fresnel zone, (c) reflected wavelet with maximum normalized energy, i.e., radius corresponding to generalized Fresnel zone, (d) reflected wavelet for radius which is large enough to allow separation of desired reflected wavelet and truncation effect, i.e., radius corresponding to zone of influence. Note that only in (d) the correct wavelet shape is reproduced.**

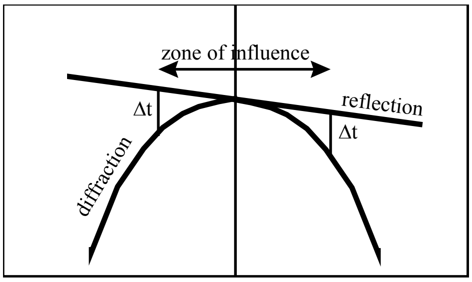

**Figure 4 Zone of influence in migration.**

*The diffraction traveltime curve defines the integration path in migration. Beyond the zone of influence the flanks of the migration operator will no longer contribute to the output point.*

In migration the zone of influence can be defined similarly (see Figure 4):

*The zone of influence is the area around the image point (point of stationary phase) for which the difference between the reflection traveltimes and the diffraction traveltimes is less than the length $\Delta t$ of the wavelet.*

The term Fresnel zone is universally used in the industry as a measure of how far to extend the migration radius, i.e., Fresnel zone is equated to zone of influence, whereas in actual fact the Fresnel zone is always smaller than the zone of influence. The zone of influence rather than Fresnel zone is to be included in 3D-survey design to define the migration fringe area.

### Illustration of Fresnel zone and zone of influence

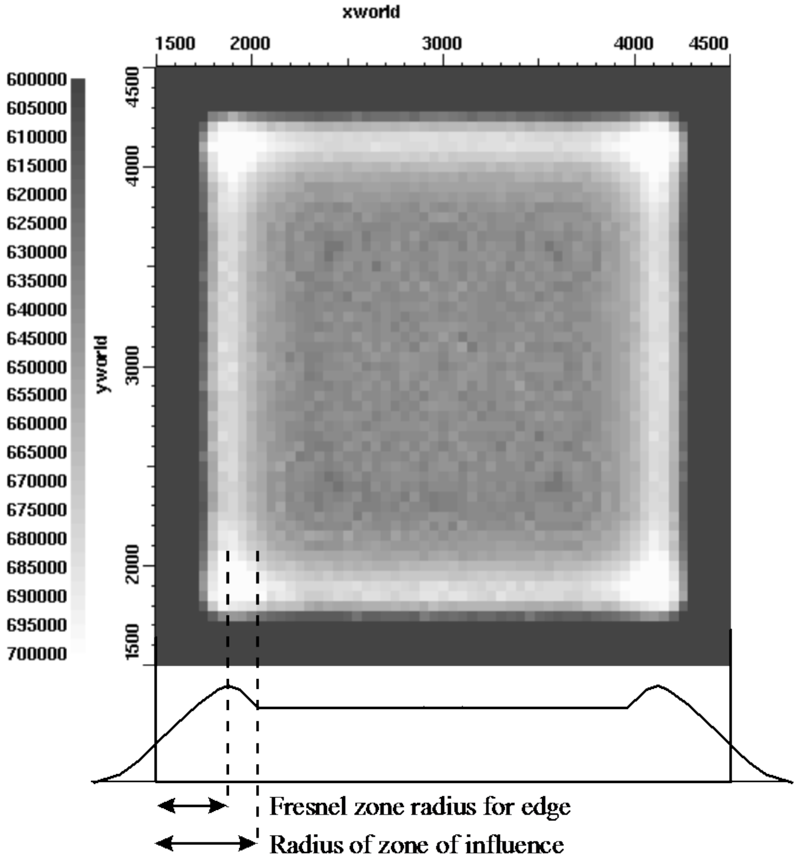

**Figure 5 Amplitude of migrated horizontal event in cross-spread. From the edge energy builds up to a maximum, indicating the radius of the Fresnel zone. A plateau of (nearly) constant amplitudes is reached beyond the radius of the zone of influence. Complete images only exist for the plateau.**

The difference between Fresnel zone and zone of influence can be illustrated using the edge effect in the migration of the data of a single cross-spread. Figure 5 shows the amplitude of a migrated horizontal event. The (single-fold) midpoint area is 3000 x 3000 m, and because the event is horizontal, the (single-fold) illumination area is the same size. However, along the edges only incomplete images can be constructed. The more data comes in, the higher the amplitude, until maximum amplitude is reached at a point, which corresponds to what could be called “the radius of the Fresnel zone for an edge”. But it takes the radius of the zone of influence before a complete image can be constructed.

The situation and interpretation given in Figure 5 is not entirely straightforward. Figure 6 is an attempt to clarify what happens along the edge of the cross-spread. For a point on the edge of the midpoint area, the situation of Figure 6c applies. There, the amplitude will only be half the amplitude as found along the plateau area. Moving toward the inside, more and more traces contribute to the output until the full amplitude is reached when the zone of influence is entirely inside the midpoint area. In between, the amplitude goes through a maximum, which might be taken to correspond to the Fresnel zone radius for edges. Normally, Fresnel zone would be a circular area for which maximum amplitude is reached. As illustrated in Figure 6, the maximum energy in Figure 5 is reached for a position, which is likely to be different than the circular Fresnel zone.

This example also illustrates that image fold is smaller than illumination fold, because the image area is smaller than the illumination area. The loss of imaging quality due to edge effects is of serious concern. In cross-spreads with adjacent midpoint areas, the edge effects of adjacent edges tend to compensate each other (Vermeer and Grimbergen, 1998), but only for horizontal events. The larger the dip, the more disjoint the illumination areas will be (cf. Figure 1), causing incomplete images in some places and overlapping images elesewhere.

### Conclusions

The introduction of continuous fold allows a better definition of illumination area, image area and corresponding illumination fold and image fold. Though Fresnel zones are important to describe interference effects, they do not provide a good measure of the build-up to complete images. The zone of influence, determined by the length of the wavelet, is the correct measure.

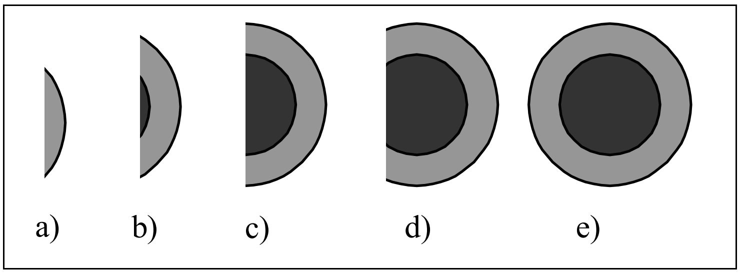

**Figure 6 Edge effect and Fresnel zone. Outer circle has radius of zone of influence, inner circle has radius of Fresnel zone.**

*e) output point well inside the midpoint area, c) output point right at the edge of the midpoint area. In this case the phase of the migrated wavelet is correct, but the amplitude is half that of the plateau level, a) output point outside midpoint area, b) and d) intermediate situations.*

## References

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