

# Forward/Inverse Radon Transform

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**Forward/Inverse Radon Transform Radon Transform** is commonly used to transform data to the Radon domain for suppression of multiples by muting or deconvolution in the Radon domain. The inverse transform is then run to convert the data back to the time-space domain.

## Theory

**Forward/Inverse Radon Transform Radon Transform** transforms the data to time-moveout space so that a suitable mute can be picked to eliminate the primary energy. The multiple energy is left, which can then be subtracted from the input data. Radon filters can also be applied such that they pass the primary energy, but in practice this has tended to produce an artificial and wormy appearing result.

The Radon transform distinguishes between primaries and multiples based on the residual moveout from near to far offset. A parabolic form of the Radon transform is used since multiples have an approximately parabolic form after NMO. An approximately hyperbolic form may also be used. This hyperbolic approximation is more accurate at times around offset=depth, but is not as accurate for shallower events as the parabolic method.

If deconvolution is applied between the forward and inverse transforms, it should be noted that events which were hyperbolic in time-offset space will be approximately parabolic after the linear radon transform. Deconvolution gates must be designed appropriately.

## Sparse Transform Option

Conventional Radon Filtering has limitations on the discrimination possible between multiples and primaries. These limitations stem from the fact that events in T-X space do not transform to points in Tau-P space, but exhibit a "butterfly" shape. The sparse transform option will reduce the size of the butterfly in the Moveout (P) direction, but can cause dispersion of energy in the time (Tau) direction. The sparse transform does this by concentrating energy on the Moveout samples which have the most energy. This

discrimination against weak events tends to reduce the effect of aliased events as well as enhance those which are desired.

In order for the sparse option to be most effective, the primaries should be flattened by applying **NMO** before **Radon Filter** or **Analysis**. This will align all of the primary energy near  $P=0$ , giving greatest weight to the primary reflections in the sparse transform. Multiple energy should be expected to fall on a variety of P-values, so the sparse solution does not reconstruct it as well as the aligned primaries. Incoherent noise and aliased energy should be diminished for this same reason.

Testing should be done to determine the optimum amount of sparseness to use for each dataset. There is a tradeoff between the fidelity of data reconstruction and the separation of events which can be obtained.

## Usage

### Input/Output

**Radon Transform** should almost always be used on CDP domain data. NMO must first be applied using the primary velocities, plus an appropriate mute to eliminate first break refractions and NMO stretch.

The output from Radon Transform is flagged as **Not matching the database** for both forward and inverse transform.

### Method

A Radon space is then computed for each CDP. **Radon Analysis** may be used to display the data as time versus residual moveout. Primaries map from offset space to zero residual moveout in Radon space. Multiples map to the positive residual moveout zone. Events that have been overcorrected are in the negative residual moveout portion of Radon space. This is why the typical range of minimum to maximum p-values for a Radon transform are biased toward the positive values that is, typically something like 100 to +400 ms.

The benefits of this method are that it requires no knowledge of the multiple generating mechanism, and unlike the F-K

demultiple processes, it attenuates multiples at all offsets equally. It also works fairly well with non-uniform geometries.

A minimum moveout of 30 ms from near trace to far trace is required for this algorithm to be effective on real data. The greater the moveout differential, the more effective the Radon Filter will be. However large moveout differentials may require more p-values over a greater range to be adequately sampled. The run time for this process increases with the square of the number of p-values, so choose this parameter with care. Radon filtering is a computationally intensive process which may require several minutes for a high fold CDP.

To remove multiples, follow these steps:

1. Apply NMO with the primary velocity function.
2. Run **Radon Analysis** on a representative set of CDPs. Pick mutes in Radon space which pass the multiples by removing the primaries, that is, a top mute should normally be picked.
3. Run the **Radon Filter** using the mute picked in Step 2.

**Note:** You must use the same number of p-values, start and end times, reference offset, and upper and lower frequency limits for this process as you used in the **Radon Analysis**. If you do not, the mutes will not be the correct mutes for the data input to this step.

The program offers the option of frequency band-limiting the data during the transform process. The run time is proportional to the bandwidth processed.

Multiple time gates are available with the Radon Filter tool, but only time-invariant transforms are possible with this tool.

## References

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- Foster, D.J., and Mosher, C.C., 1992, Suppression of multiple reflections using the Radon transform: Geophysics, 57, 386-395.
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Sacchi, M.D. and Ulrych, T. J., 1995. High resolution velocity gathers and offset-space reconstruction: Geophysics, 60, 1169-1177.

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## Parameters

### ***Direction of transform***

Select the desired direction for radon transform:

- **Forward** radon transform
- **Inverse** radon transform

### ***Number of p-values***

This appears if **Forward** to **Direction of transform**. Enter the number of traces in the radon transform space. A typical value might be in the range of 20 to 40. The number of p-values should be at least as large as the maximum fold of the input ensembles. Too low a value will generate streaks on the output. Too large a value may greatly increase runtime.

### ***Minimum p-value of interest (ms)***

Enter the minimum p-value of interest representing the largest likely overcorrection on the data at the far offset. A value of around -100 ms is recommended as a starting point. You should allow for slight irregularities in the velocity functions. In other words, the primaries may show a slight overcorrection. The primary reflection wavelet has a finite length, which must also be accounted for by this value.

### ***Maximum p-value of interest (ms)***

Enter the maximum p-value of interest representing the largest likely undercorrection on the data at the far offset. A value of around 400 ms is recommended as a starting point. The actual value will depend on the geographical location of the survey, the velocities of the multiple energy, and the

offsets used in recording the data. Select the maximum value seen on the data for undercorrected multiples, and add about 100 ms margin.

**Note:** All coherent events on the data should fall between the minimum and maximum p-values of interest. If coherent energy falls outside of this range the least-squares fit will attempt to model it into the range of p-values supplied and this will result in artifacts on the output.

### ***Minimum time of interest (ms)***

Enter the start time of the window on the input data. The transform will only be performed at times greater than this minimum time. The output data at time less than this will be zero.

### ***Maximum time of interest (ms)***

Enter the end time of the window on the input data. The transform will only be performed at times less than this maximum time. The output data at times greater than this will be zero.

### ***Minimum frequency of interest***

Enter the minimum coherent frequency, in Hz. Frequencies less than this value will not be modeled in radon space.

### ***Maximum frequency of interest***

Enter the maximum coherent frequency, in Hz. Frequencies greater than this value will not be modeled in radon space.

### ***Type of transform to perform***

Select the type of radon transform by setting the power that offset is raised to. Options are:

- **Parabolic** approximates a hyperbola.
- **Hyperbolic** uses a hyperbola for events at depths equal to the reference offset.
- **Linear** is used to attack linear noise or to make reverberations periodic by angle of incidence,  $p$ . This is a method of computing what has been called a slant stack.

**Parabolic** and **Hyperbolic** are normally used for multiple rejection. Hyperbolic has greater error than Parabolic for shallower events, but less error for deeper events.

### ***Reference offset for delta moveout***

Enter the reference offset to which the minimum and maximum p-values and mutes have been referenced. A larger residual moveout is expected for larger offsets, hence the need to define a reference which is used for definition of the mutes in this process and in **Radon Analysis**. P-values are expected to vary with the square of the change in reference offset.

### ***Minimum number of traces/ensemble to transform***

Enter the minimum number of traces per ensemble to transform. Transformed traces are set to zero if number of traces per ensemble is less than this number. The default is 5.

### ***Damping for radon solution***

This appears if **Forward to Direction of transform**. Enter a fractional amount of damping to stabilize the matrix solution of radon space from input data space. For typical datasets, set the damping to a value between 0.01 and 0.1. Higher values are appropriate for noisier data.

If the damping is set less than 0.01, it is assumed that the data are very clean, such as synthetics. An alternative matrix solution may be used depending on the stability of the matrix at each frequency. Results may be significantly different compared with higher levels of noise.

### ***Time gate length for Radon solution (ms)***

Enter a time gate length in ms for sparse radon.

### ***Compute a sparse (Hi-res) radon solution?***

Select **Yes** to compute a sparse radon transform. The sparse solution is an iterative solution which will take more time to compute, but can give sharper definition of events along the moveout axis. Sparse inversion constructs a sparse Radon domain solution that also reconstructs the input data in a least-squares sense.

### ***Sparseness parameter***

This appears if **Yes** to **Compute a sparse (Hi-res) radon solution**. Enter the amount of sparseness in the solution measured as a fraction of the main matrix diagonal. Use values between 0 and 1.0. A larger value will give a solution which is sparser in the moveout axis. Values between 0.05 and 0.2 should be tested.

### ***Sparseness stability parameter***

This appears if **Yes** to **Compute a sparse (Hi-res) radon solution**. Enter a value between 0.0001 and 0.1. Test the values until you find a correct solution for your data. A smaller value allows a sparser solution to be computed. This parameter (measured as a fraction of sparseness parameter) avoids division by zero. It has a similar, but opposite, effect to the **Sparseness parameter**.

### ***Reapply trace mute after filter?***

This appears if **Inverse** to **Direction of transform**. Select **Yes** to reapply any top and bottom mutes that were applied prior to the radon transform. Select Yes to avoid artifacts of the filtering from extending into zones that should be zero.

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