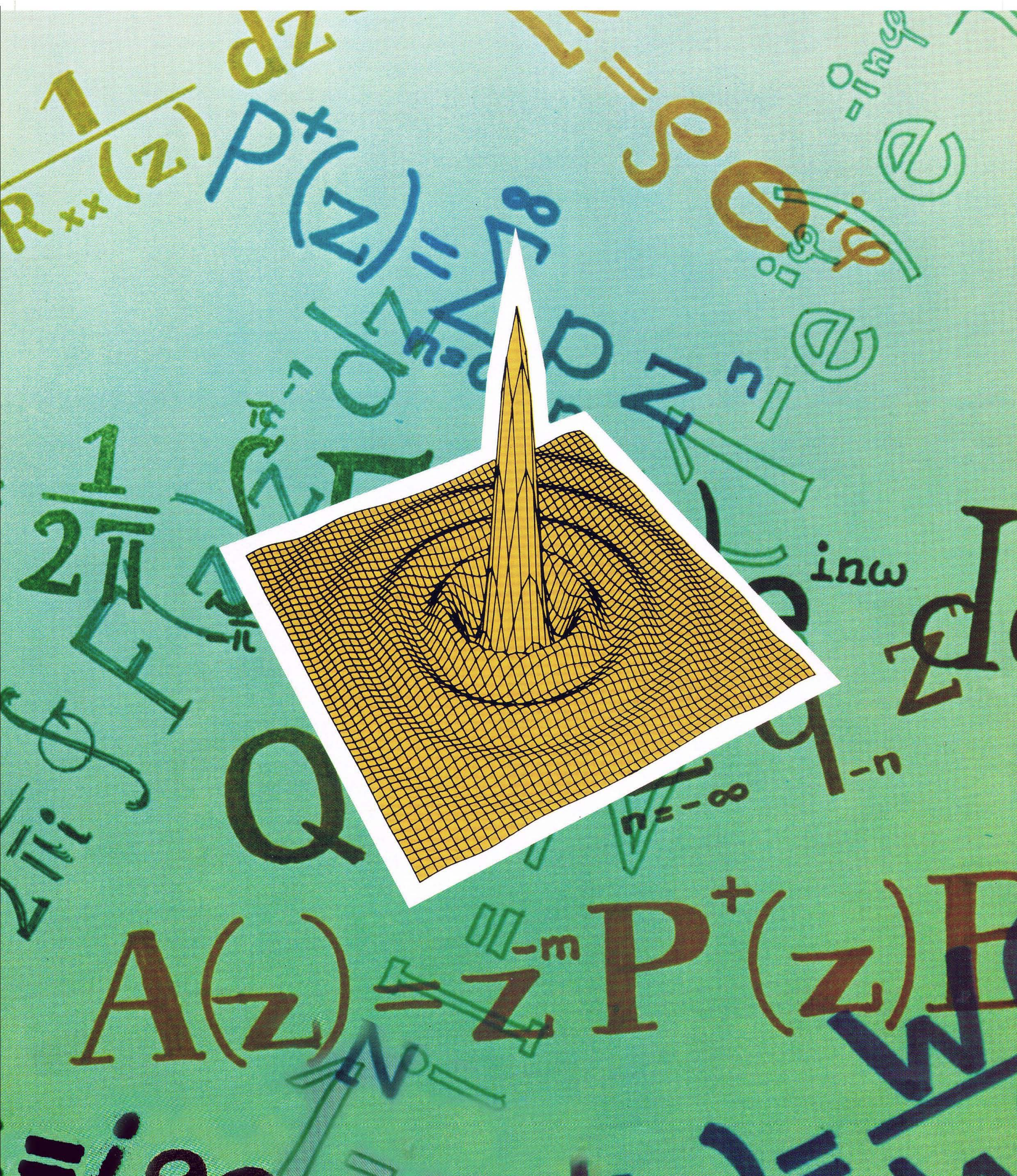
PRAKLA-SEISMOS INFORMATION No. 29

Modern Digital Filters



Modern Digital Filters

The Seismic Time Series as Linear Filter Model

As seismic time series or a section of a time series can be represented simply and clearly by a linear filter model:

$$x(t) = r(t) * w(t) + n(t)$$

*represents convolution or filtering

$x(t)$ – seismic time series (seismic trace)
$r(t)$ – reflectivity function
$w(t)$ – seismic signal (wavelet)
$n(t)$ – additive noise

The signal is a composite waveform

$$w(t) = w_1(t) * w_2(t) * w_3(t).....$$

the individual wavelets of which are shown in the illustration at the right. The individual wavelets can be defined as individual filter operators.

Depending on the problem at hand one or more individual wavelets have to be transformed (shaped) to give another wavelet yet to be defined. This can be carried out with the help of an optimal shaping filter. Thereby the resulting wavelet (more preciscely: the desired output) is intended to produce more favourable conditions for the subsequent processing or interpretation.

In the ideal case one hopes to define the reflectivity function r(t) from the seismic series. This is unfortunately only realizable to a certain extent, as not **all** components comprising the seismic trace are known and as the presence of noise interferes with the survey data.

TSR-Filter Technique

The transformation of a known wavelet into a desired wavelet with help of a linear filter is called "shaping". The corresponding transformation-operator is called "shaping-filter".

Shaping-filter with finite impulse response (FIR)

Digital filters are often applied by convolving the time series with the weighting function of finite length. With respect to the design of FIR- operators two problems arise:

For the computation of a filter operator which is of infinite extension, an optimum length of truncation has to be selected. Having chosen the length of the inverse operator, the problem is to find the optimum lag with respect to the pre-given length of the filter operator (length selection problem, lag selection problem).

Shaping-filter with infinite impulse response (IIR, TSR)

It is also possible to filter a time series recursively. In this case each output sample is computed as a weighted sum of previously computed output samples. It can be shown, for this case, that the impulse response of this recursive filter is of infinite length.

Furthermore, recursive filters with only forward recursion have to be distinguished from recursive filters with forward and reverse recursion. The latter we define as two-sided recursive filters = TSR-filters.

With the TSR-filter there is neither a length selection problem nor a lag selection problem. Of course the theory of recursion filters requires the minimum delay property of the denominator part for both, i.e. forward and reverse recursion.

But this is easily established by an additional correlation step. From this correlation step the autocorrelation function of the input waveform on the trace is established. Therefore the necessary denominator operators are easily derived from the minimum-delay factorization of the corresponding autocorrelation function.

It is possible to circumvent this correlation step, but this implies the factorization of the known wavelet into its minimum- and maximum delay components. This can be done for instance by using the cepstrum of the known wavelet, or, in the time domain by explicit computation of the zeroes of its z-transform.

So in summary the following possibilities are available:
– the finite length shaping filter (FIR-filter)
– the one-sided infinite length shaping filter (IIR-filter)
– the two-sided infinite length shaping filter = TSR-filter

PRAKLA-SEISMOS has intensively studied and developed the TSR-filter technique and solves all arising filter problems with the TSR-filter approach. Skilled application of recursive TSR-filter results in

- high accuracy, combined with relatively low effort.

Seismic Trace

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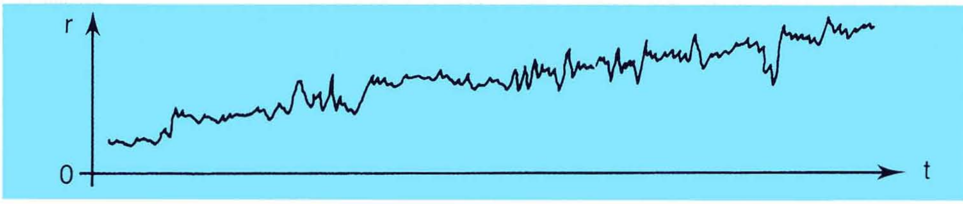
Reflectivity



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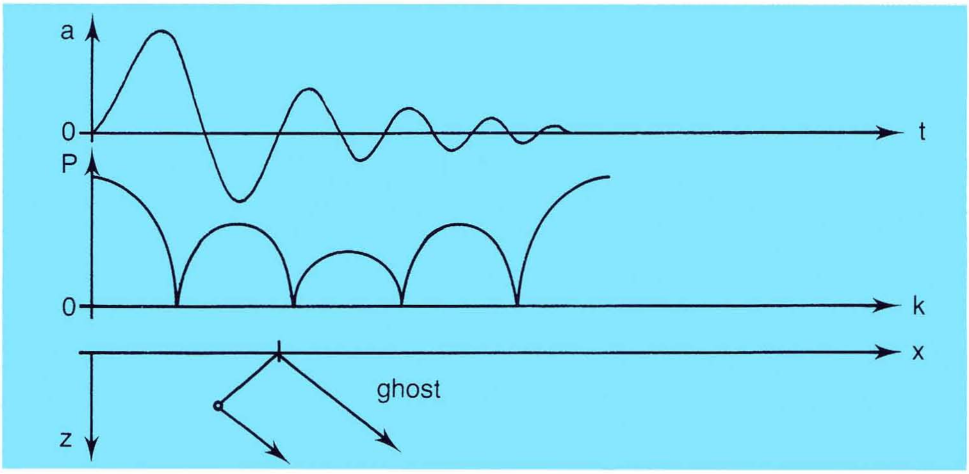
Source Filter

source pulse
farfield
sweep
....
....
....
source pattern
source coupling
source ghost
....
....
....



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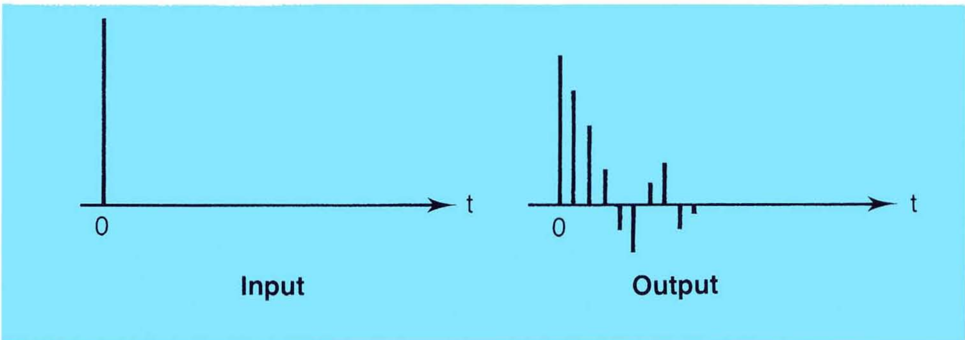
Earth Filter

multiples
attenuation
dispersion
mode conversion
reverberation
....
....
....



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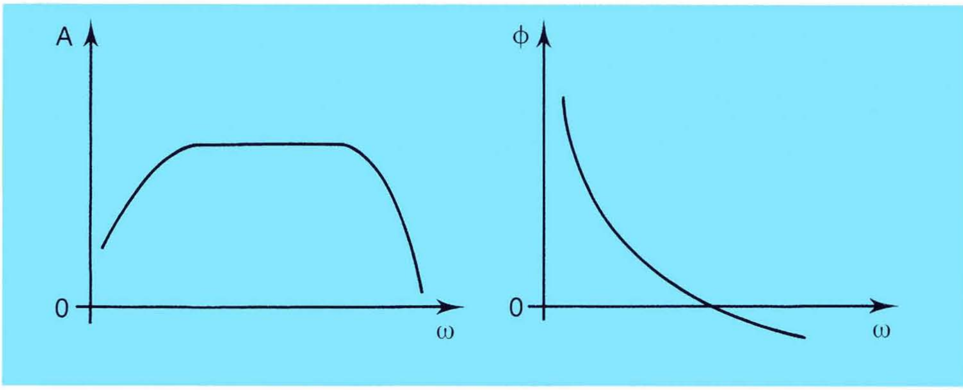
Receiver Filter

receiver array
receiver ghost
recording system
cable response
recording filter
type of geophones
....
....
....



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Seismic Noise

wind
rain
ground roll (dispersive)
....
....
....

Examples for Filters

1. Conventional noise rejection filters

- Band pass filter (single channel filter) for incoherent noise
- Notch filter (single channel filter) for mono-frequency noise
- FAN filter (multi channel filter) for coherent noise.

2. Shaping filter

Looking at the **source filters,** we have as possible applications (Source Signature Filters):

- Transformation of farfield signal to minimum delay
- Replacement of VIBROSEIS* field correlation by a modified Sweep correlation (e.g. base plate sweep correlation)
- Debubbling
- Correction for source variations
- Correction for different sources (e.g. VIBROSEIS*/ Dynamite)
- ....
- ....
- ....

*Trademark of Conoco Inc.

Looking at the **earth filters,** we have as possible applications:

- Deghosting filter
- Compression of dispersed signals (e.g. channel waves, surface waves)
- ....
- ....

Looking at the **receiver filters,** we have as possible applications:

- Dephasing
- Correction for different recording filters
- Correction for different geophone types
- ....
- ....

3. General wavelet transformation

- Conventional Deconvolution
- Spectrum Filter
- Transformation to zero-phase (e.g. improved resolution for interpretation, or as basis for pseudo-log computation)
- Phase-adjustment to match well-data with seismic data
- Increase of band width of seismic data for improved resolution
- ....
- ....

4. Further application of the TSR-shaping filter

Occasionally the problem of approximating an ideal filter characteristic shows up.

Also two dimensional TSR-filters may be implemented; a corresponding low pass operator is shown on the front cover.

For this type of problem the TSR-filter approach also offers an optimum solution. TSR-filter implementations are available for e.g.

- Integration Filter
- Differentiation Filter
- Hilbert-Transform Filter
- Phase Shift Filters
- ....
- ....
- ....

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