Advanced Signal Processing

Dealing with ocular artifacts
Understanding digital filters
Latency Jitter
Examples with real data!

Ocular Artifacts

- The problem
  - Eye movements and blinks create a potential that is propagated in volume conducted fashion
  - Manifests in recorded EEG
- Why?
  - Eye not spherical; more rounded in back
  - Potential is therefore positive in front with respect to rear of eye
  - Movements = Moving dipole
  - Blinks = sliding variable resistor

Ocular Arifacts

- Eye-blinks are ***systematic*** noise with respect to the ERP signal
  - Occur at predictable latencies
  - Are meaningful variables in and of themselves:
    - John Stern: Information processing and blink latency
    - Peter Lang: Blink Amplitude and affectively modulated startle response

Ocular Artifacts

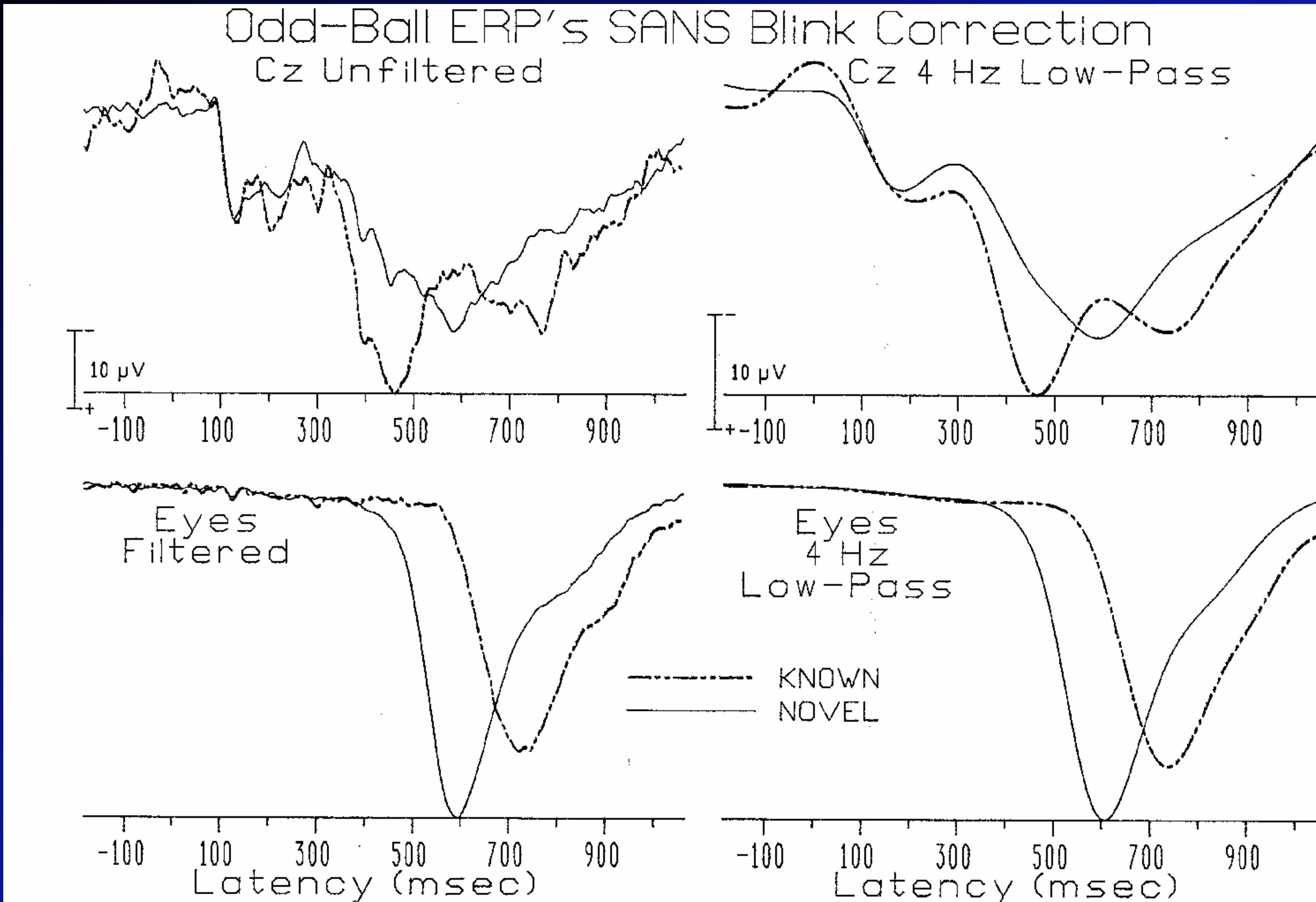
- Signal averaging will not remove this "noise" (noise wrt signal of interest)
- Average waveform a(t) is mixture of timelocked signal s(t) and randomly distributed error (noise)

$$a(t) = s(t) + \frac{\sum_{1}^{n} e(t)}{n}$$

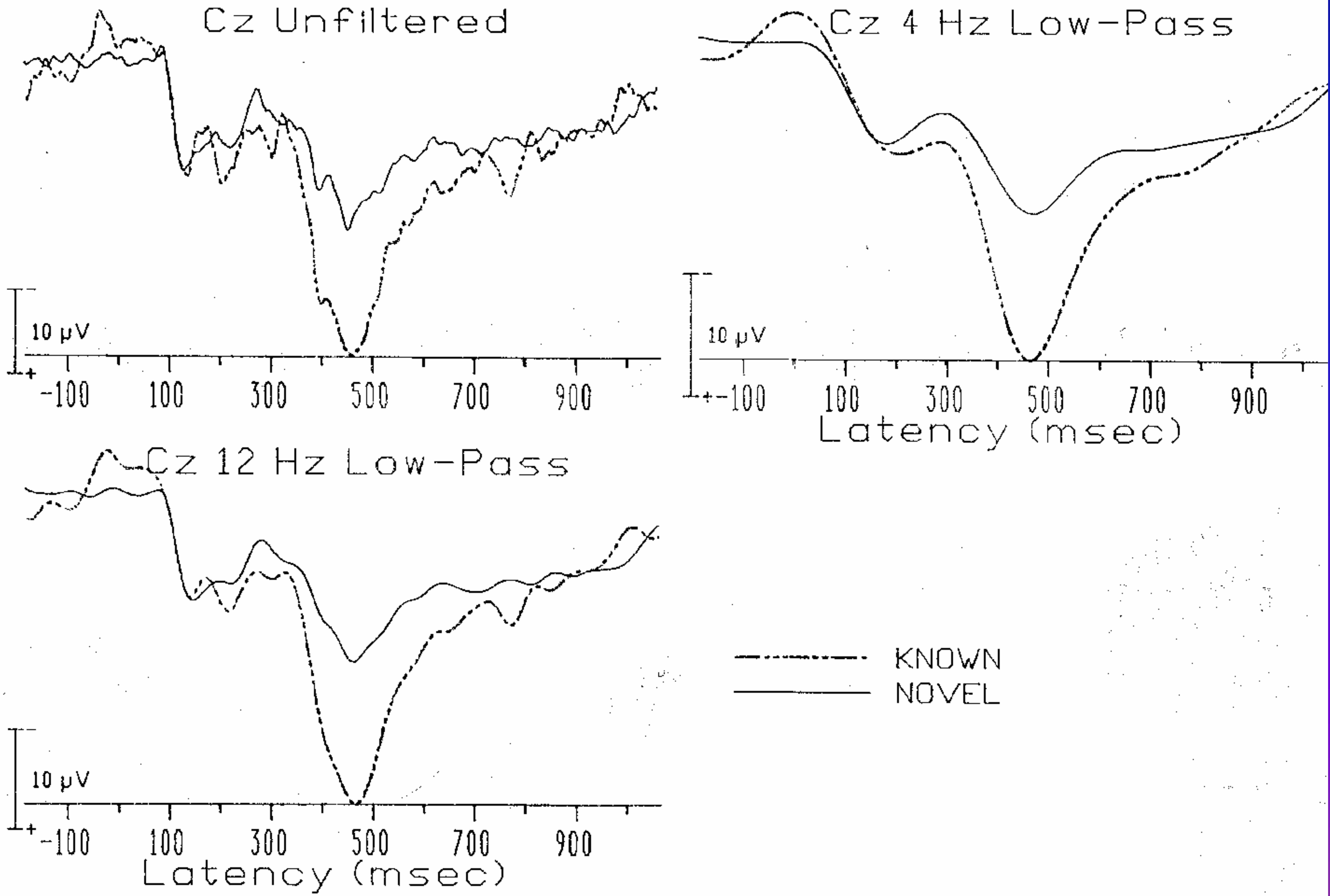
- If non-ERP signals are random with respect to stimulus onset, then the latter term will approach zero with sufficient trials (n)
- If not, the latter term will not sum to zero, but will include time-locked noise
- Noise will therefore average IN, not average OUT

Ocular Artifacts

- Eye-blinks tend to occur at the cessation of processing.
  - Recall that the P300 is also a good index of cessation of processing.
- As a result, eye-blink artifact tends to appear as a late P300ish component

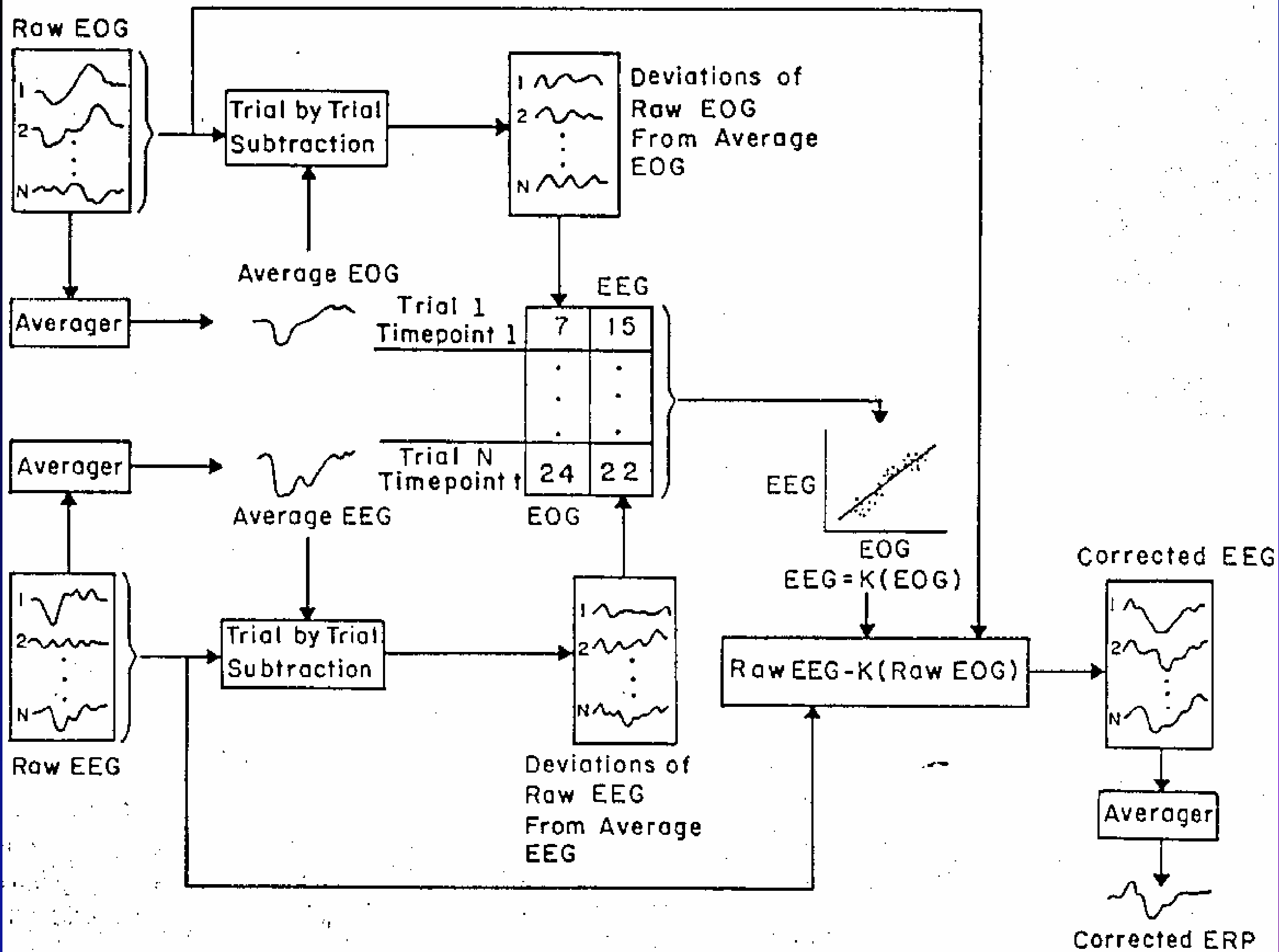

Odd-Ball ERP's SANS Blink Correction
Cz Unfiltered
Cz 4 Hz Low-Pass
10 μV
10 μV
-100
100
300
500
700
900
Eyes Filtered
Eyes 4 Hz Low-Pass
KNOWN
NOVEL
Latency (msec)
Latency (msec)

Odd-Ball ERP's WITH Blink Correction



What to Do?!

- Reject trials during which eye-blink occurred.
  - Problems:
    - Trials which elicit blinks may not be equivalent to those which do not.
    - Large data loss, may be unable to get usable average
- Eye-blink correction (Gratton, Coles, & Donchin, 1983)
  - Assumes that the effect of an eye-movement or blink on the recorded EEG can be inferred from activity recorded near the source of the artifact (top and bottom of eye, e.g.)



Raw EOG
Trial by Trial Subtraction
Deviations of Raw EOG From Average EOG
Average EOG
Averager
Trial 1 Timepoint 1
EEG
7
15
Averager
Trial N Timepoint t
24
22
EOG
Average EEG
EEG
EOG
EEG=K(EOG)
Corrected EEG
Trial by Trial Subtraction
Raw EEG-K(Raw EOG)
Raw EEG
Deviations of Raw EEG From Average EEG
Averager
Corrected ERP

The Details

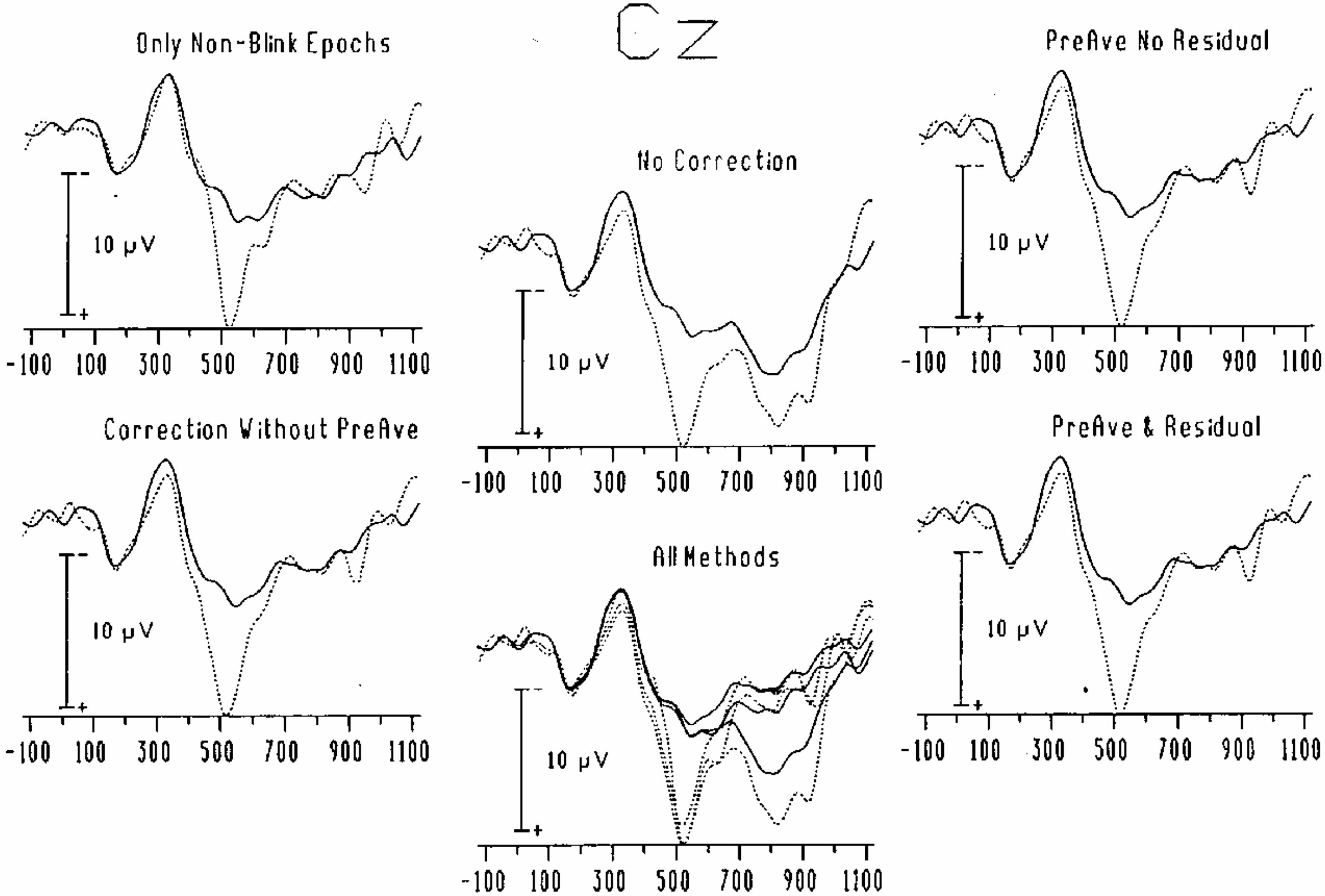
- Must determine extent to which EOG signal propagates to various scalp loci
  - Propagation factors computed only after any event-related activity is removed from both EOG & EEG channels
  - Event related activity in both channels may spuriously inflate estimate of propagation
  - Based upon correlation and relative amplitudes of EEG & EOG, a scaling factor is computed. The scaling factor is then applied on a trial by trial basis as follows:

Corrected EEG = Raw EEG - K*(Raw EOG)

- Corrected EEG epochs then averaged together to get blink-corrected ERP

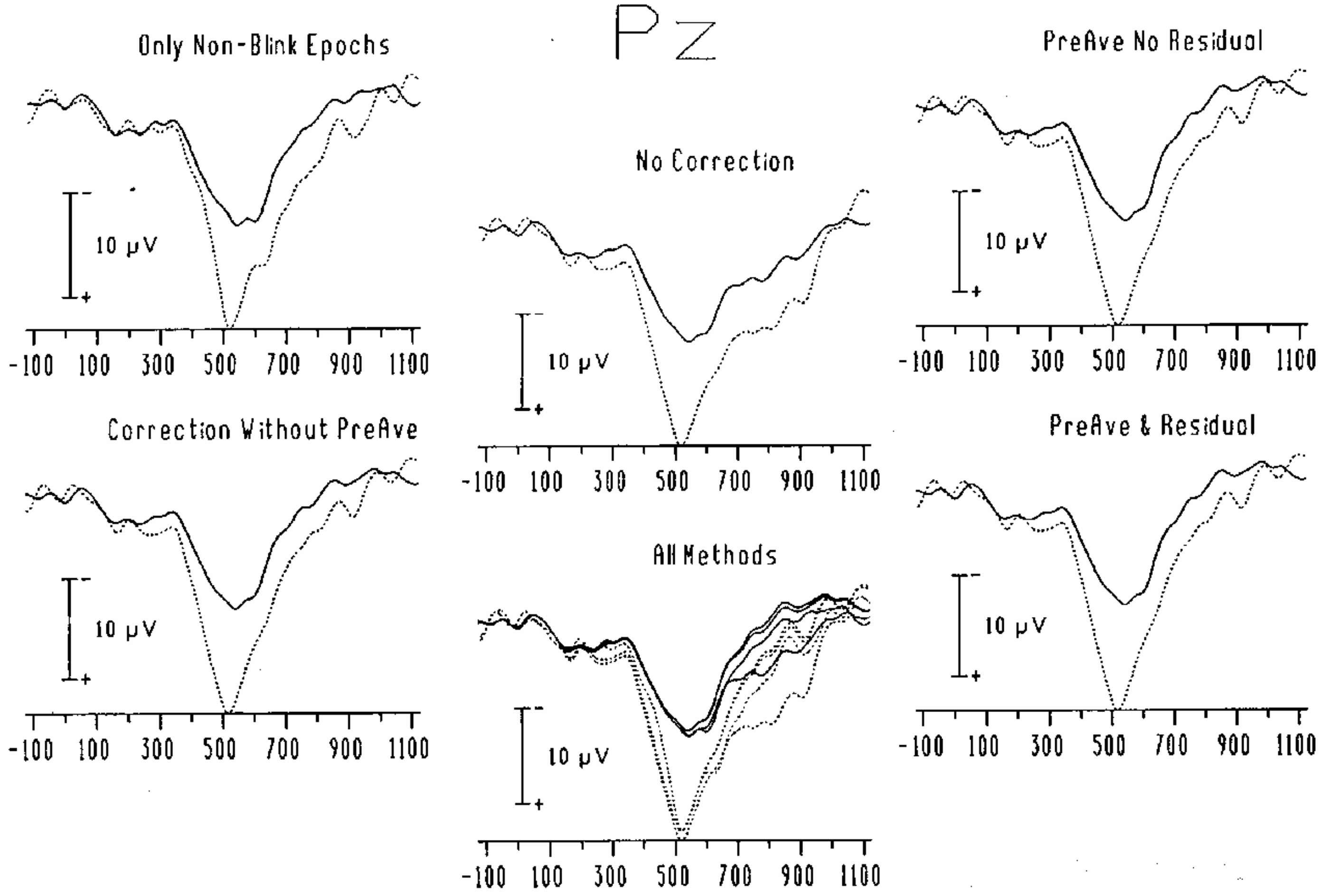
Validity of Ocular Correction

- Can produce valid results, but important to examine data to ascertain how well procedure worked.
- Variant of Gratton et al devised by Semlitsch, Anderer, Schuster, and Presslich (1986).
  - Creates blink-locked averages
  - Should reduce event-related contributions to correction estimate
  - Produces highly similar results



Four methods of undetermined validity for dealing with Blink Artifact in an Oddball Paradigm. Solid lines represent frequent novel items, and dotted lines represent rare learned items.

"Only Non-Blink Epochs" = excluding blink-contaminated epochs (28/60 Learned, 34/150 Unlearned)
"Correction without PreAve" = Gratton et al. method without the preliminary subtraction of event-related activity
"PreAve No Residual" = Gratton et al. method, event-related activity extracted prior to correction, no residual correction
"PreAve & Residual" = Gratton et al. method, event-related activity extracted prior to correction, with residual correction
For comparison, non-corrected data and all methods are presented in the center column. Abscissa is latency (msec).



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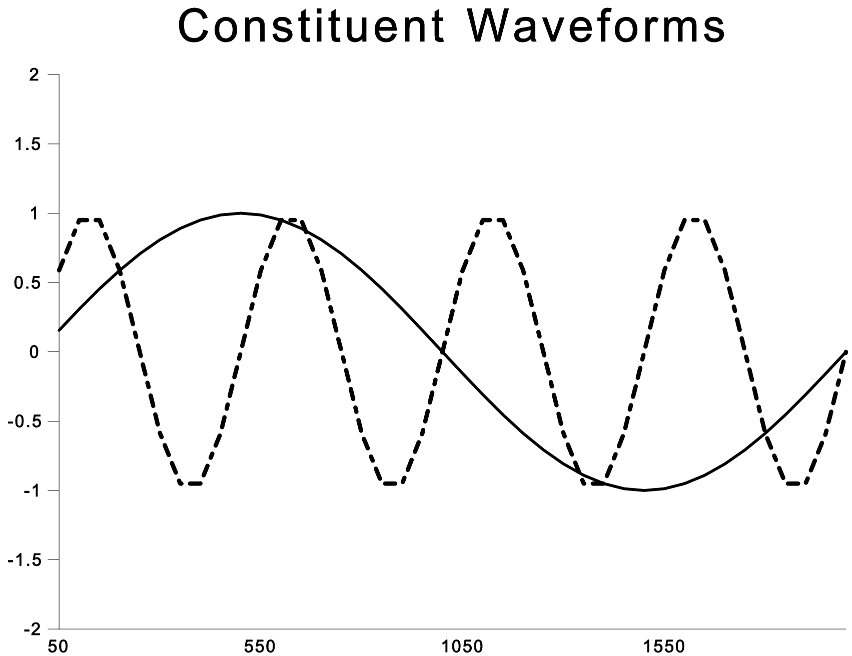
Other Methods (in brief)

- Most other methods also depend upon subtraction of a proportion of the EOG signal or some transformation of the EOG signal
  - Frequency-domain methods recognize that not all frequencies in the EOG channel propagate equally to scalp sites
  - Source localization methods attempt to derive a source that represents the equivalent of the origin of the eye potentials, and then compute the extent to which these sources would project onto scalp

Demonstration of Ocular Correction
Later in Lecture

Digital Vs. Analog Filtering

- Analog filters can introduce the problem of phase shift or lag, with certain frequency components "lagging" behind the others
  - This is the effect of a capacitor literally slowing a signal
  - Some frequencies are slowed more than others
  - this can pose a problem in ERP recording, as some components would be distorted
- Hence, digital filtering is a preferred alternative.
  - No phase shift
  - Becoming widely used


Constituent Waveforms
2
1.5
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-1
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50
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1050
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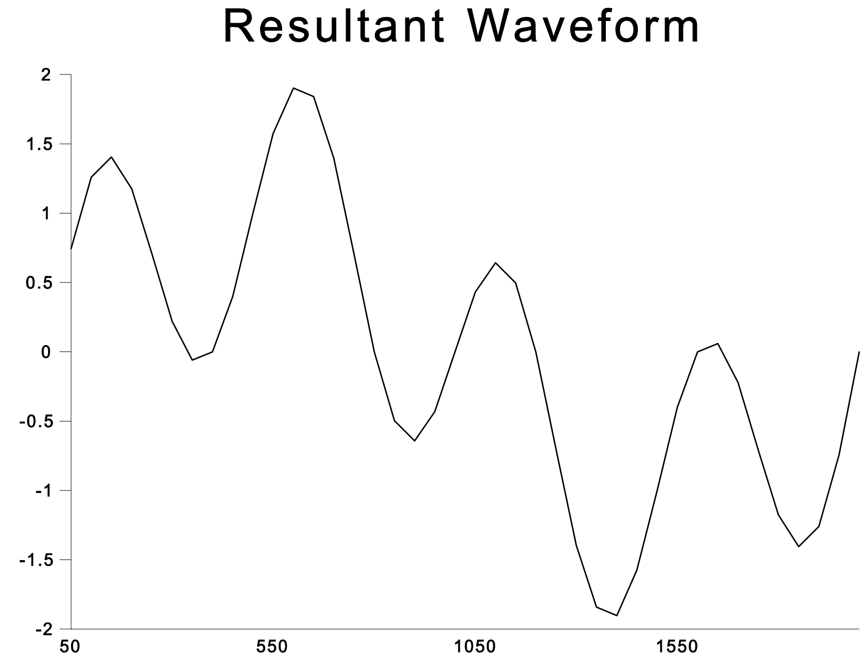
Resultant Waveform
2
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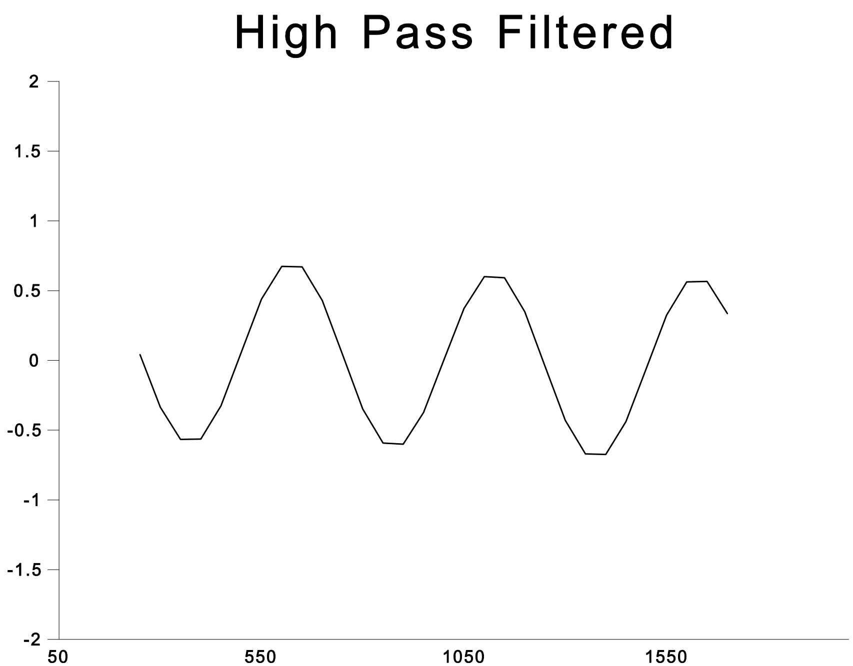
High Pass Filtered
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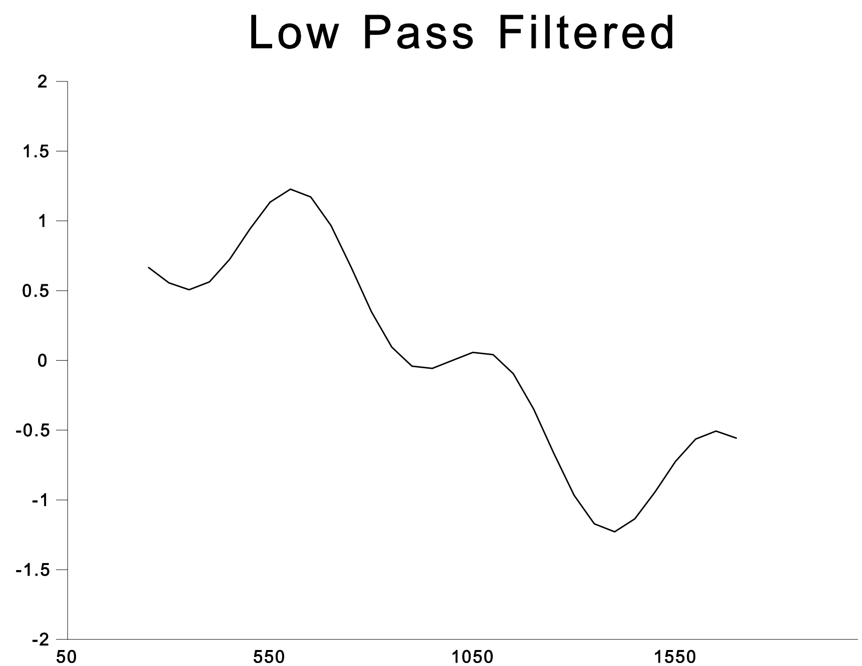
Low Pass Filtered
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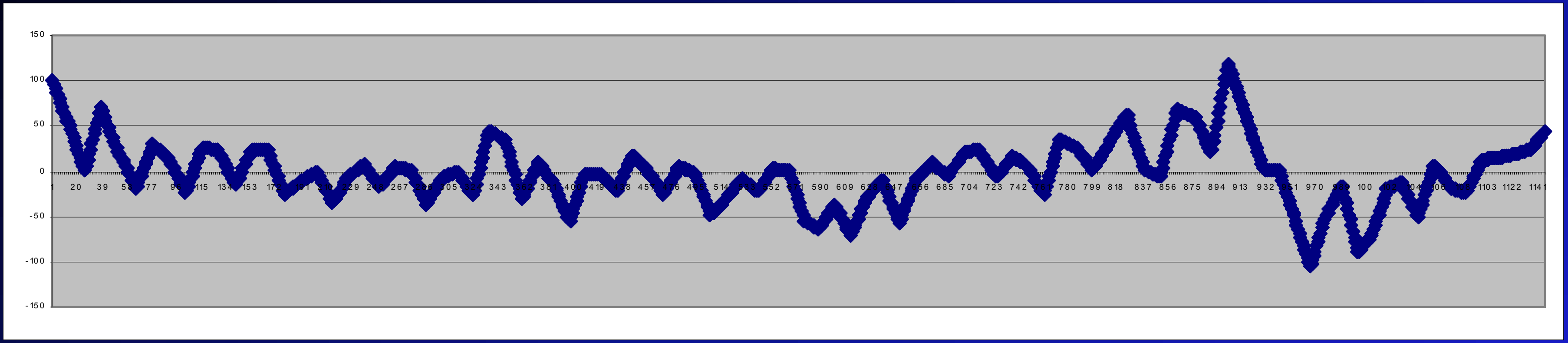
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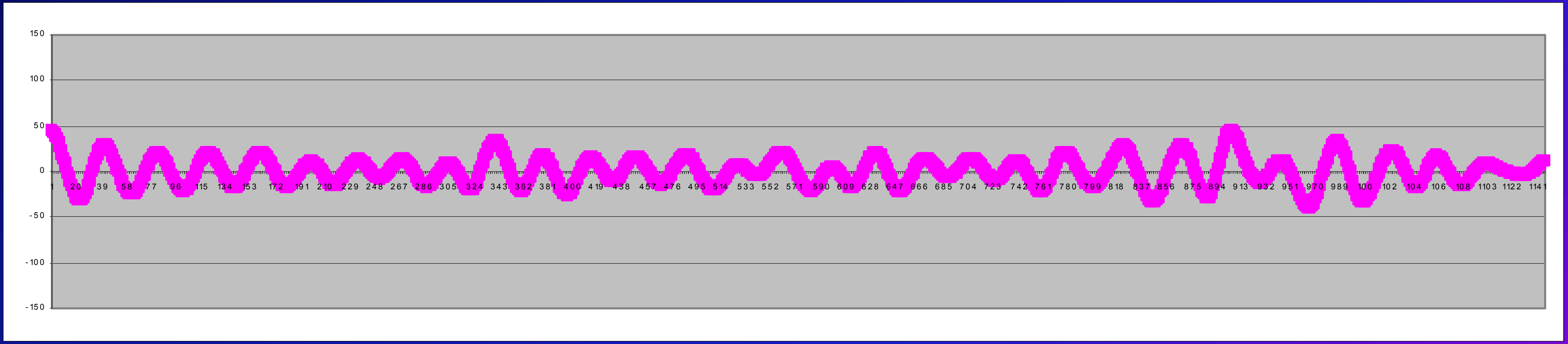
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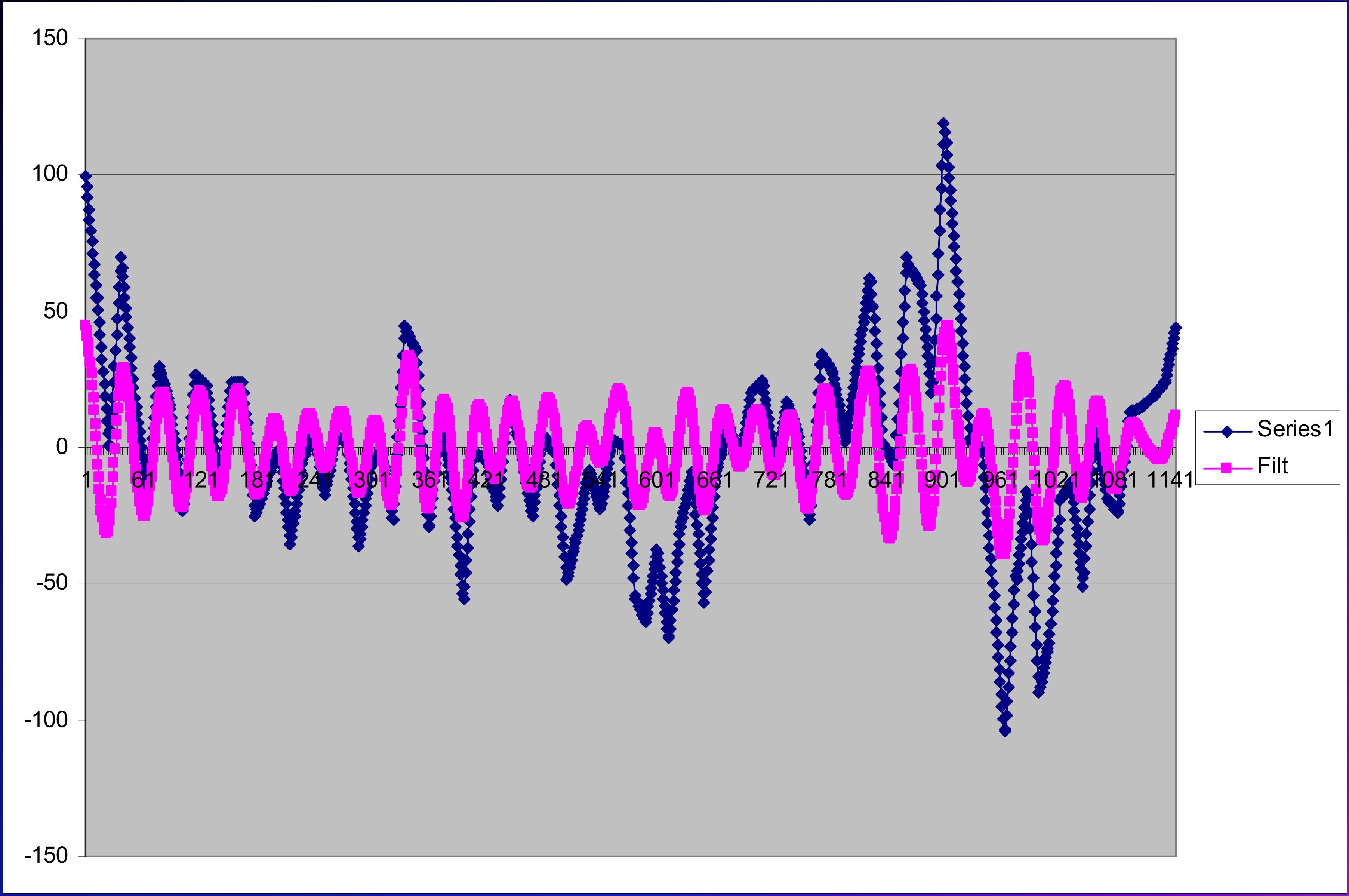
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181
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361
421
481
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601
661
721
781
841
901
961
1021
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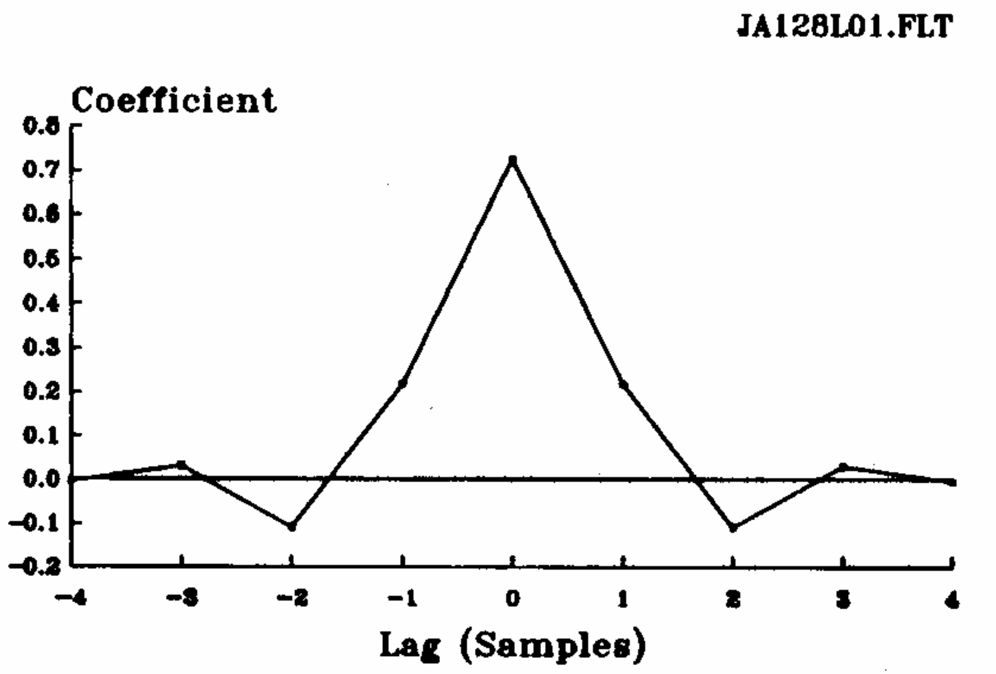
1141
Series1
Filt

One more example

The Details!

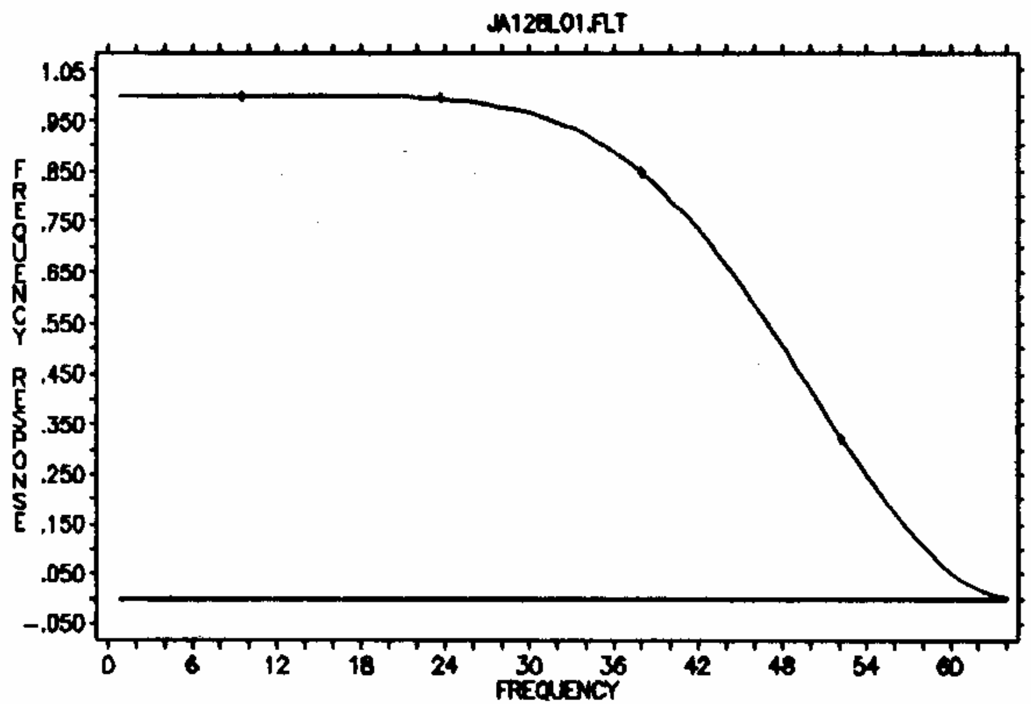
- Handout on Digital Filtering

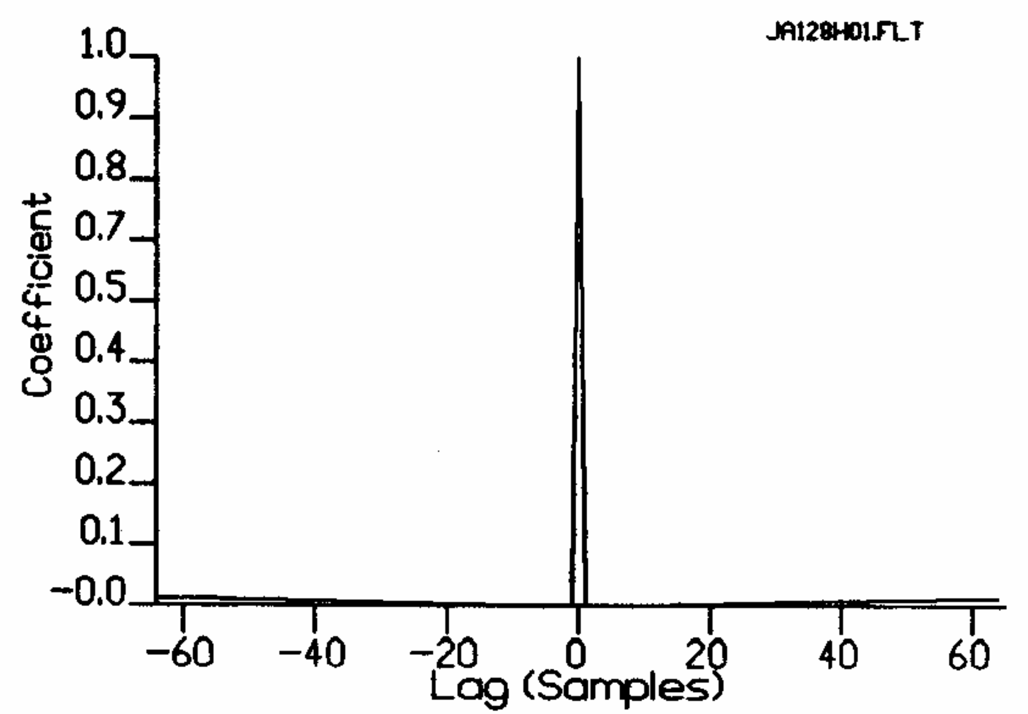
Some filters and their Transfer Functions



Transfer Function

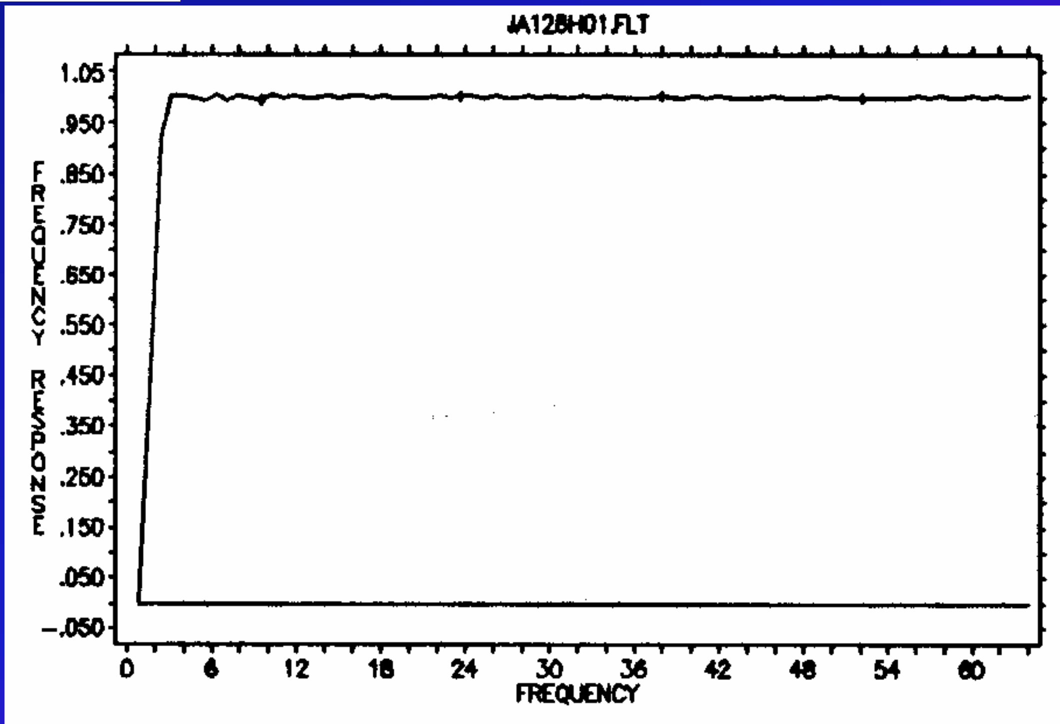
Impulse Response

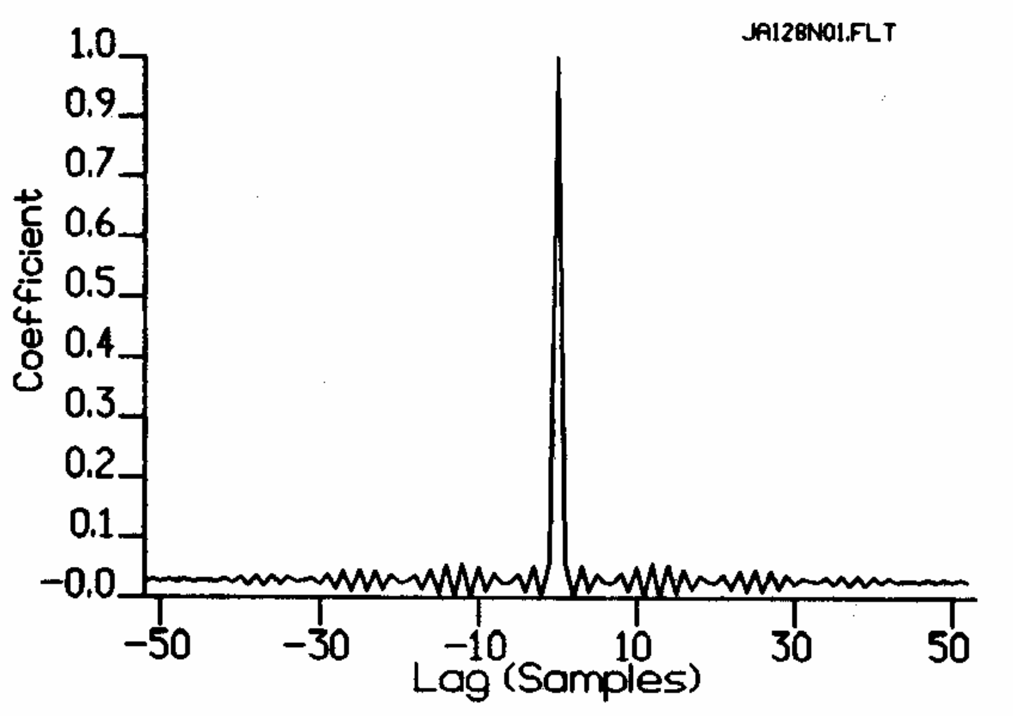




Transfer Function

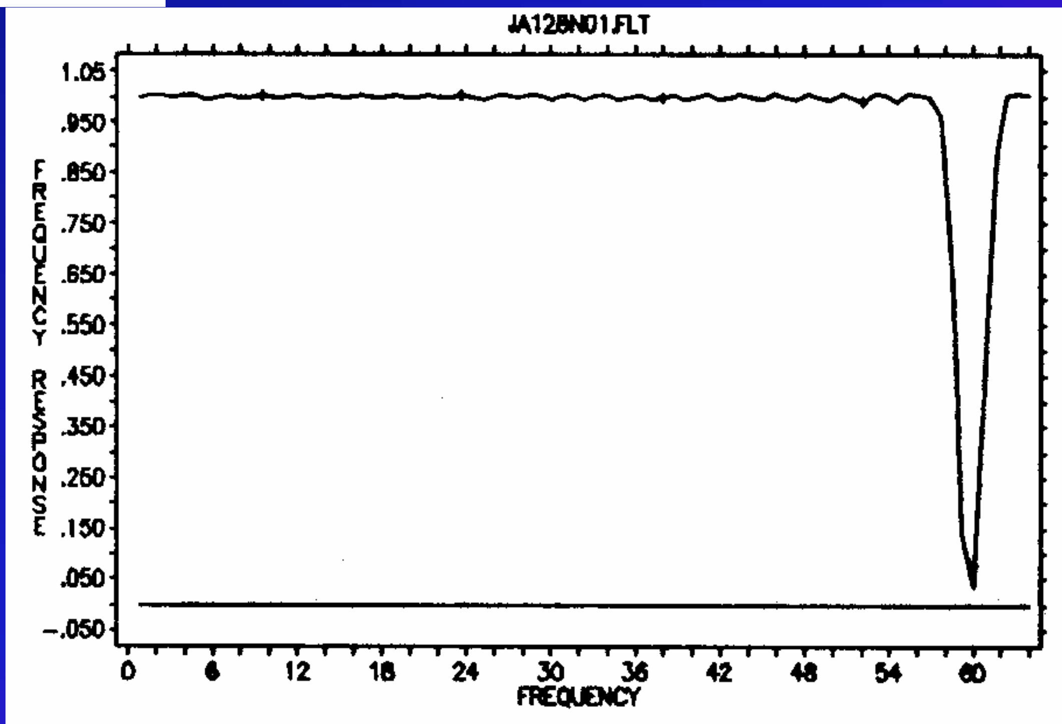
Impulse Response

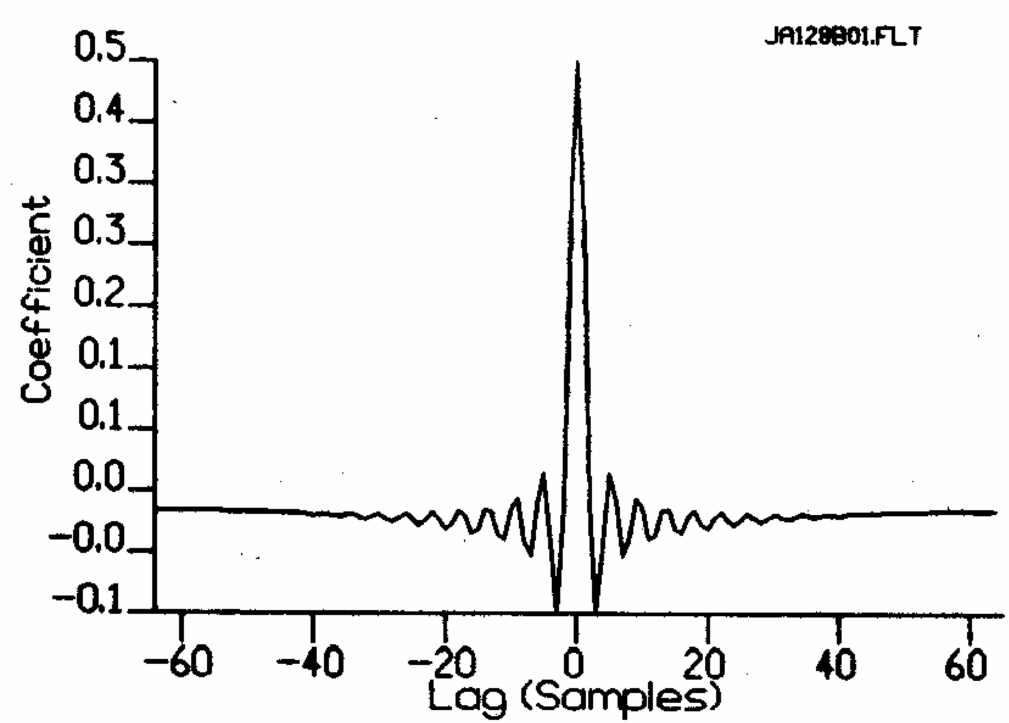




Transfer Function

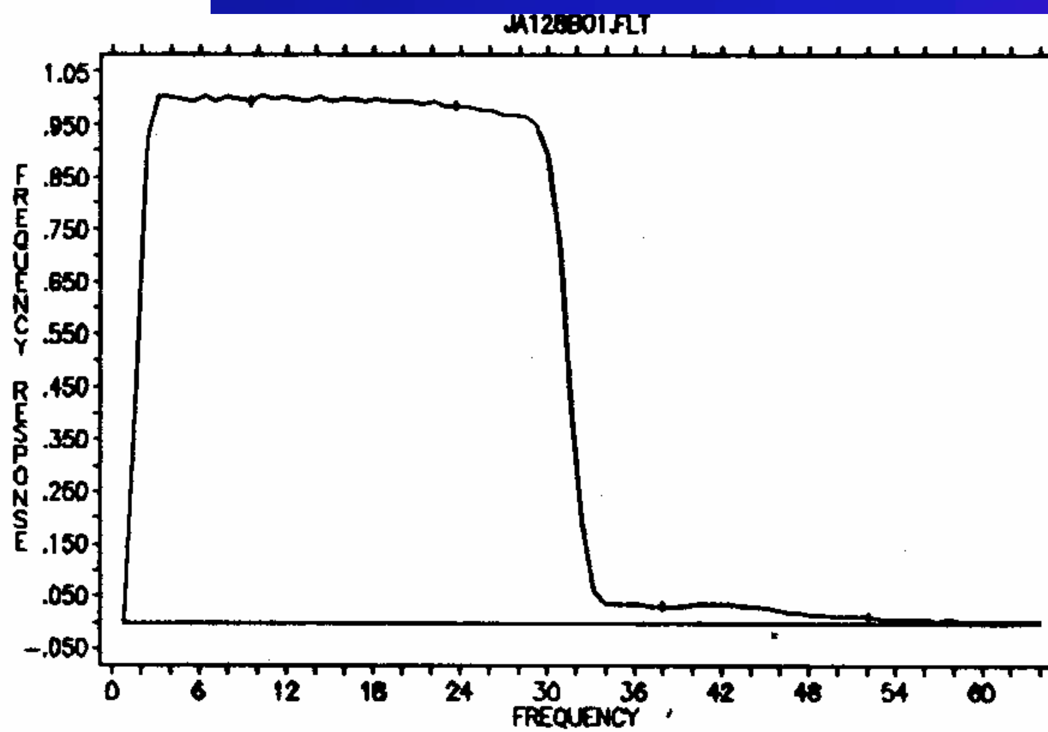
Impulse Response





Transfer Function

Impulse Response

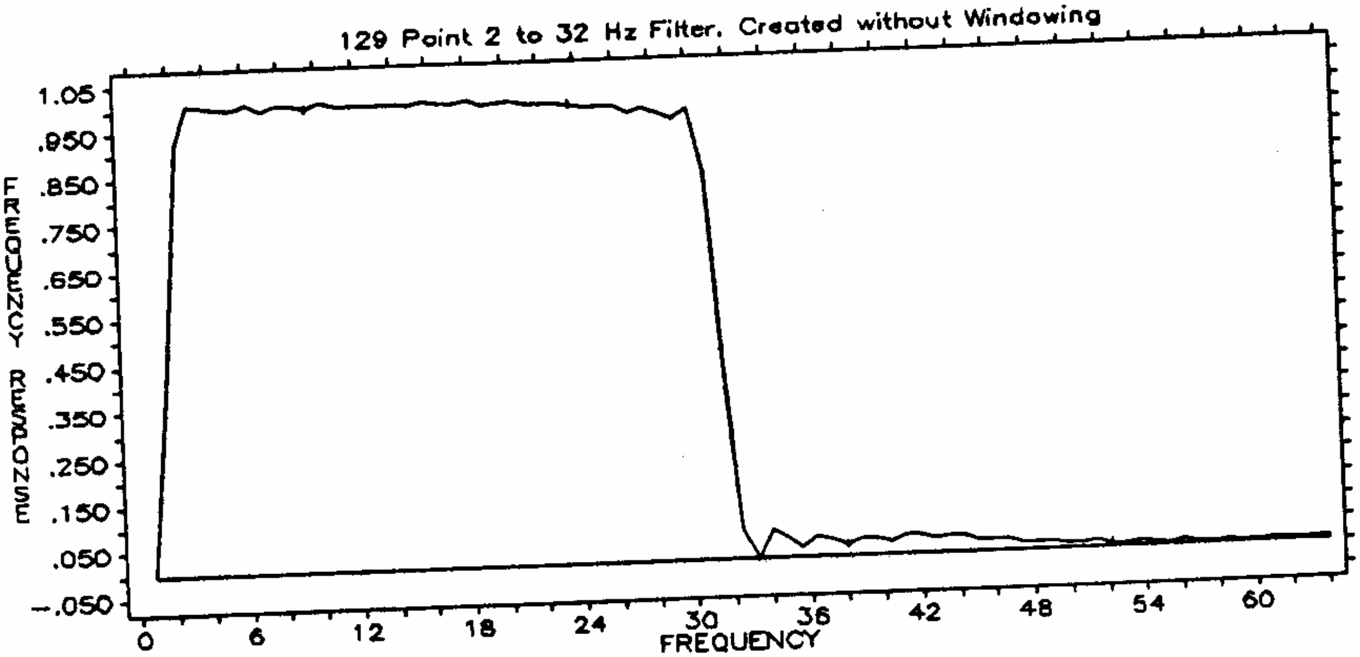


Pragmatic concerns

- Sample extra data points; many if you want sharp roll-off
- Try out your filter via FFT analysis or via derivation of the transfer function before you apply it routinely

Convolution of Filters

- If you have filters that do desirable things, but neither does it all, you can convolve filters upon one another:
- Since filter's have endpoints near 0, you can "pad" the ends with 0's so as not to lose data points
- Windowing an option



The effects of windowing on broadening the transfer function, but reducing bandpass ripple

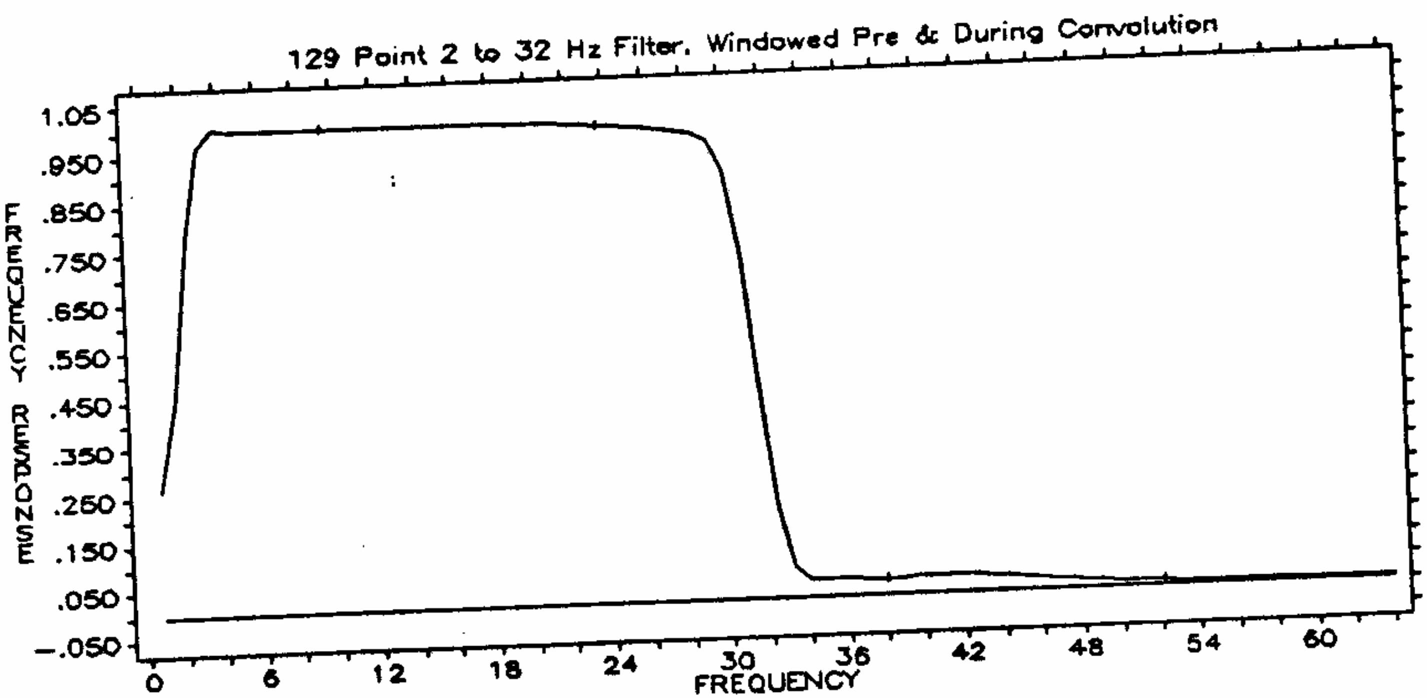
Hamming Taper, for i coefficients $-j$ to $+j$,

$\text{WinFilt}(i) = \text{NonWinFilt}(i) * w_i$

where:

$w_i = .54 + .46 * \cos(\pi p_i)$

$p_i = i/(j+1)$



Use in Single Trial Analysis

- With stringent digital filtering, you may be able to discern peaks on an individual trial basis
- Let's Try

The Problem of Latency Jitter

- The averaging assumption of invariance in signal is not always warranted
  - Especially for the later endogenous components
  - To the extent that the signal varies from trial to trial, the average will produce potentially misleading results
- Two common possibilities:
  - Smearing of components;
    - will underestimate amplitude of component (especially a problem if comparing groups, one group with more latency jitter)
  - Bimodal or multi-bumped components

The Solution

- The Woody Adaptive Filter (Woody, 1967)
- Based on Cross-correlation
  - Assumptions less restrictive than averaging methods
    - Waveform (morphology) must be constant across trials
    - Latency need not be constant

Details

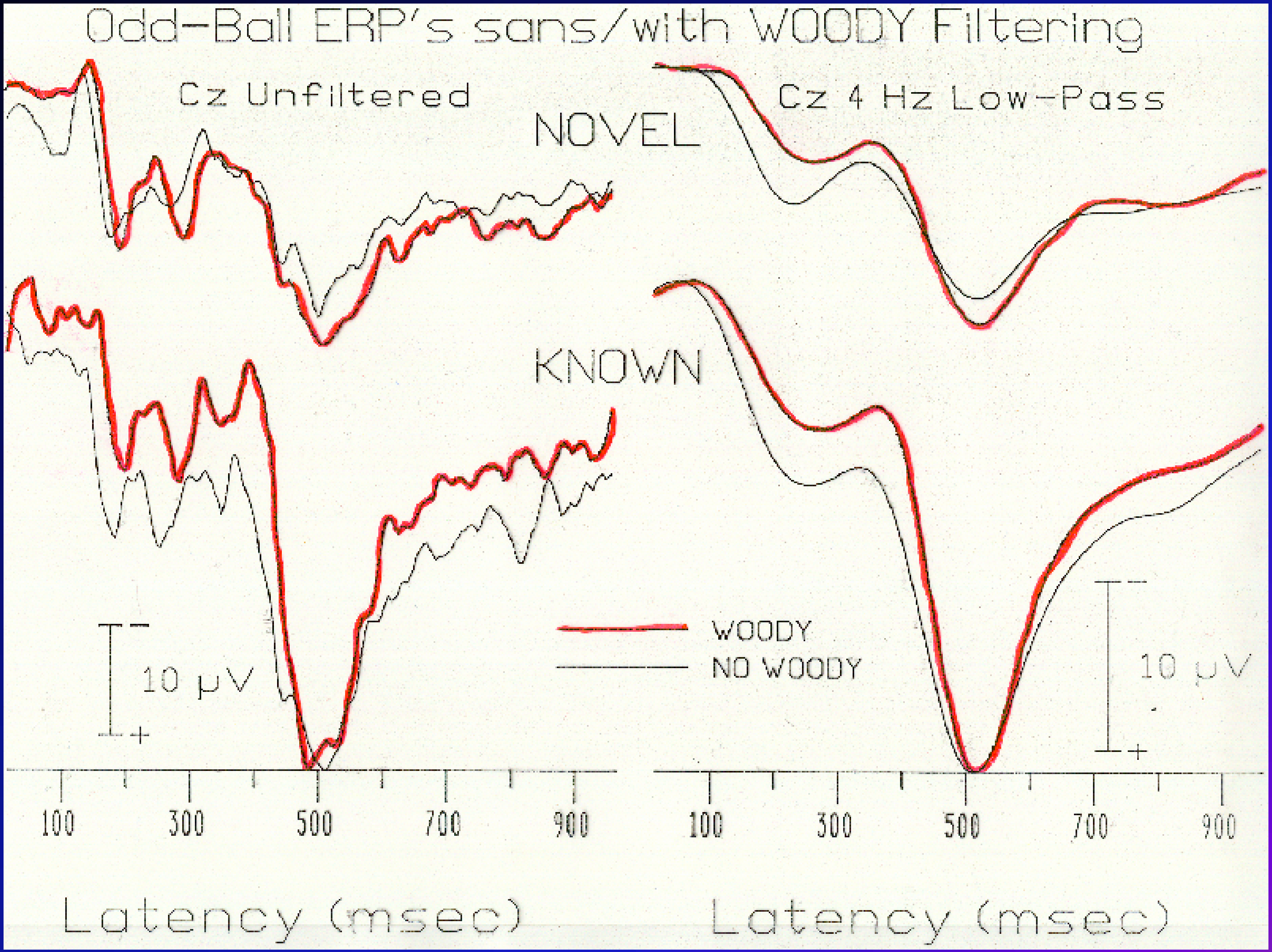
- Cross-correlational series
  - For two waveforms the correlation between each of them is computed
    - first with no lag in time (a1, a2, ..., an with b1, b2, ... bn)
    - then with one lagged with respect to the other (a1, a2, ..., an with b2, b3, ... bn+1)
  - A series of correlation values is obtained by progressively increasing the size of the lag

More Details

- Can be used as a "template matching" procedure
- Compare running average with raw EEG epochs
- This is a method of single-trial signal detection:
  - First create a template: either predetermined (e.g., sine wave) or empirically determined (e.g., average)
  - Then calculate cross-correlational series between each raw EEG epoch and the template
  - If some maximum correlation achieved, conclude signal is present
  - If correlation not achieved conclude absent
  - This can also be used as a method of determining the latency of a component (by examining the trial-by-trial shifts), or of determining the variability in response for a given individual (again by examining the trial-by-trail shifts)

Woody's Instantiation

- The Woody Adaptive Filter (Charles Woody, 1967) is a special case and application of cross correlational technique
- The term "adaptive" refers to the fact that the template is not established a priori, but generated and updated by an iterative procedure from the data themselves
- Procedure
  - Initial template is usually either a half cycle of a sine or triangle wave, or the unfiltered average of single trials
  - Cross-lagged correlations (or sometimes covariances) are then computed between each trial and this template **over a limited range of samples** (explain, e.g., region of P300, not over "invariant" components)
  - Each trial is then shifted to align it with the template at the value which yields the maximum cross correlation (or covariance)
  - A new template is then generated by averaging together these time-shifted epochs
  - Procedure is repeated using this new average as the template
  - repeated until the maximal values of the cross correlation become stable
  - often, average cross-correlation value increment monitored; if $\underline{r}$ increases < .005 or .001, then stability achieved
- Some implementations, trials which do not reach a minimum criterion (e.g., .30-.50) are discarded from subsequent template construction and perhaps from subsequent analysis altogether


Odd-Ball ERP's sans/with WOODY Filtering
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Latency (msec)
Latency (msec)

Validity

- Seems to do a fair job of improving signal extraction if a few iterations are used and if the original signal itself is singly peaked
- Wastell(1977) reports a decline in the validity of the procedure if numerous iterations are used
- Therefore, unlike averaging, Woody filtering can only improve signal-to-noise ratio over a definite limit
- Suggests also that Woody may not be the solution under conditions of very low signal-to-noise ratio

Putting it Together: Sample Analysis

- ❑Re-reference (LM, VEOG)
- ❑Ocular Artifact Correction (and Maps)
- ❑Filtering
- ❑Epoching
- ❑Baseline Correction
- ❑Averaging (100, 101, Comparison, note VEOG too)
- ❑Comparisons (Diff, T-Scores, Maps, Filters)