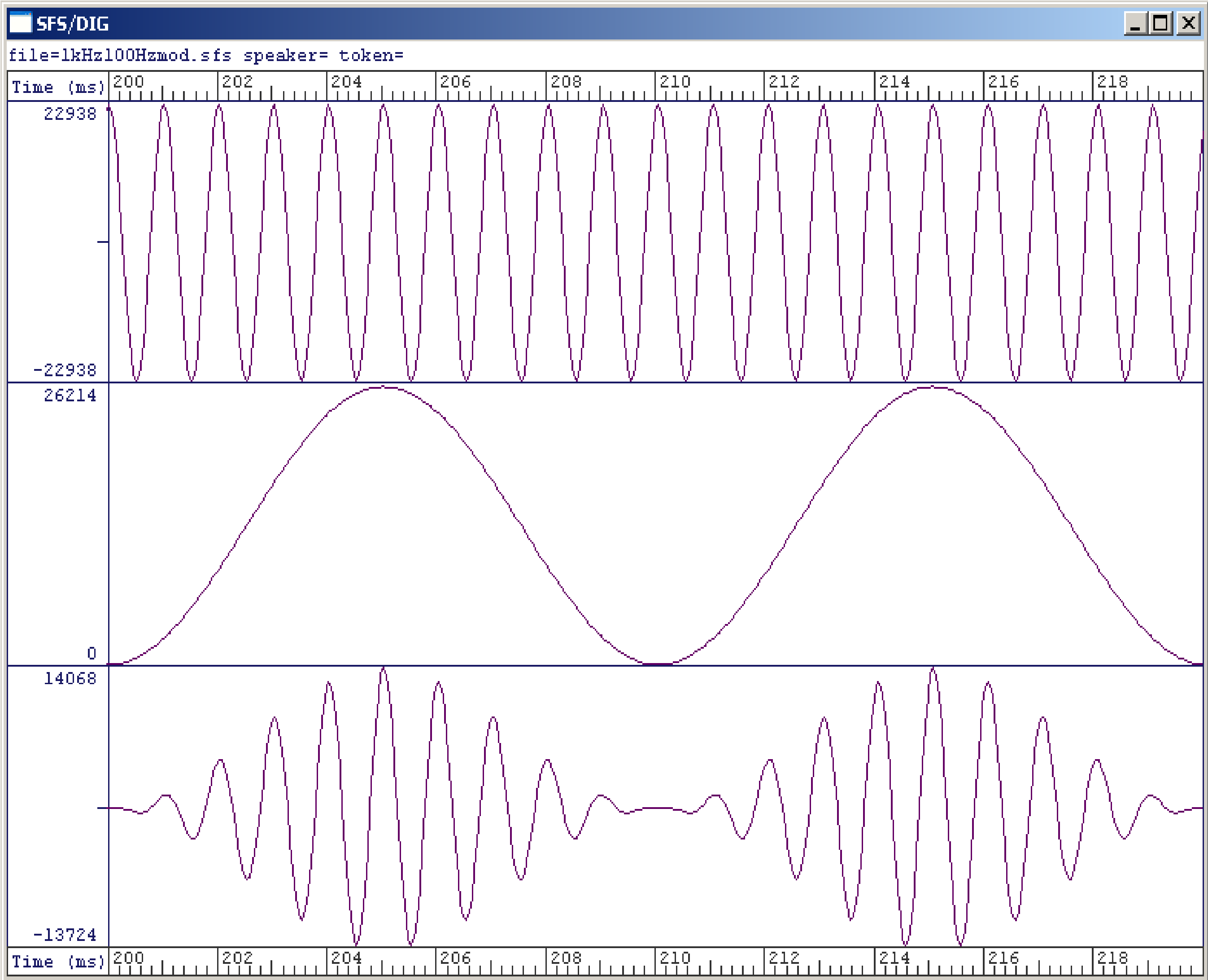
AUDL 4007 &GS12
Auditory Perception

Temporal resolution

Modulating a sinusoid



carrier at 1 kHz
(fine structure)

x

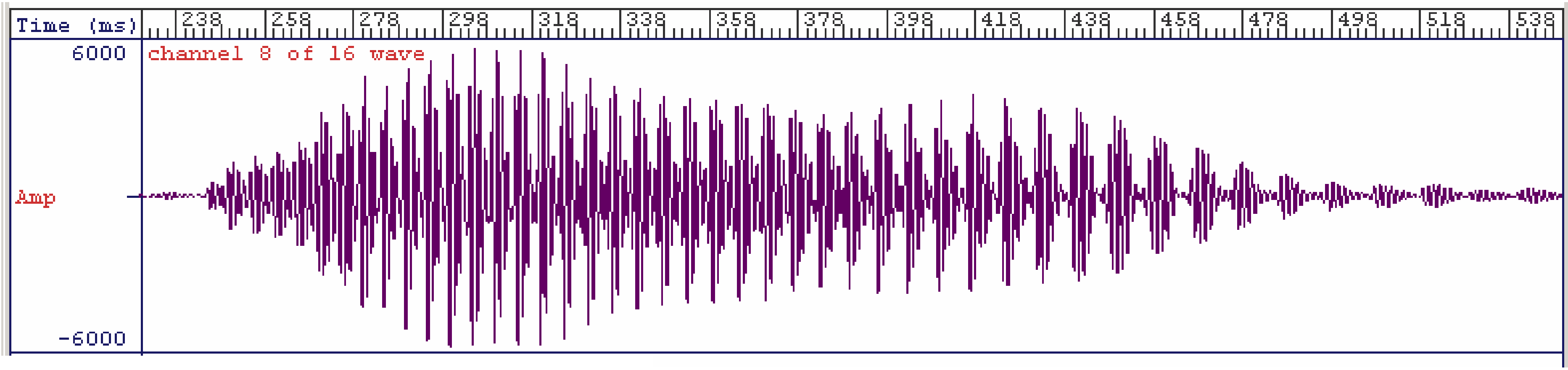
modulator at 100 Hz
(envelope)

=

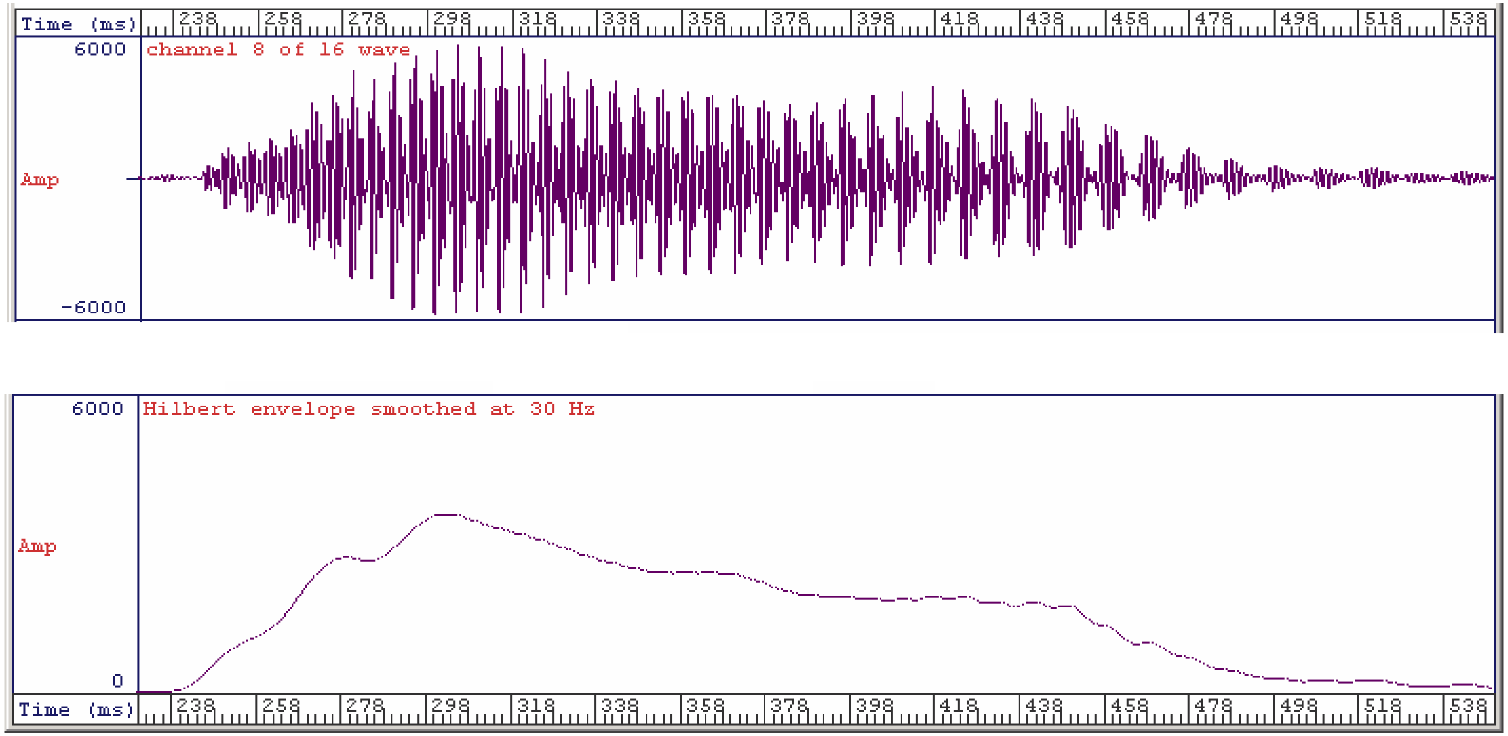
amplitude-modulated wave

Domain of temporal resolution

- Fine structure and envelope
  - fine structure – relatively fast – reflects spectral components of sounds in the sound waveform, and periodicity (in some definitions)
  - envelope is the slower stuff
  - think of all waves as being made by multiplying an envelope against a carrier



Fine structure and envelope



Envelope – reflects changing amplitude of signal e.g., over multiple cycles for periodic sounds

Caveat about ‘temporal resolution’

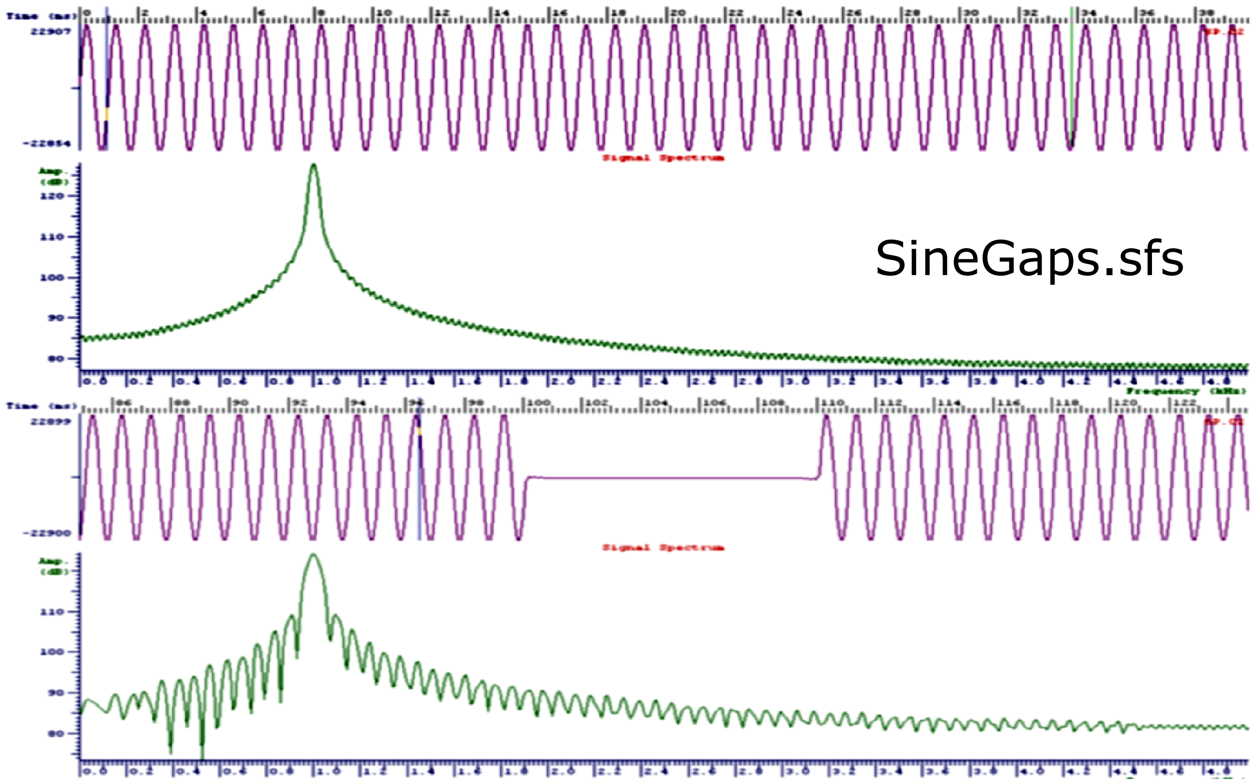
- Typically defined as reflecting perception of variations over time in …
  - *envelope* (and there are different ways to define envelope)
  - rather than *fine-structure*
- But at least in theory, could concern temporal variations, for example, in frequency of a sinusoid

Temporal Resolution for envelope most often tested in two ways

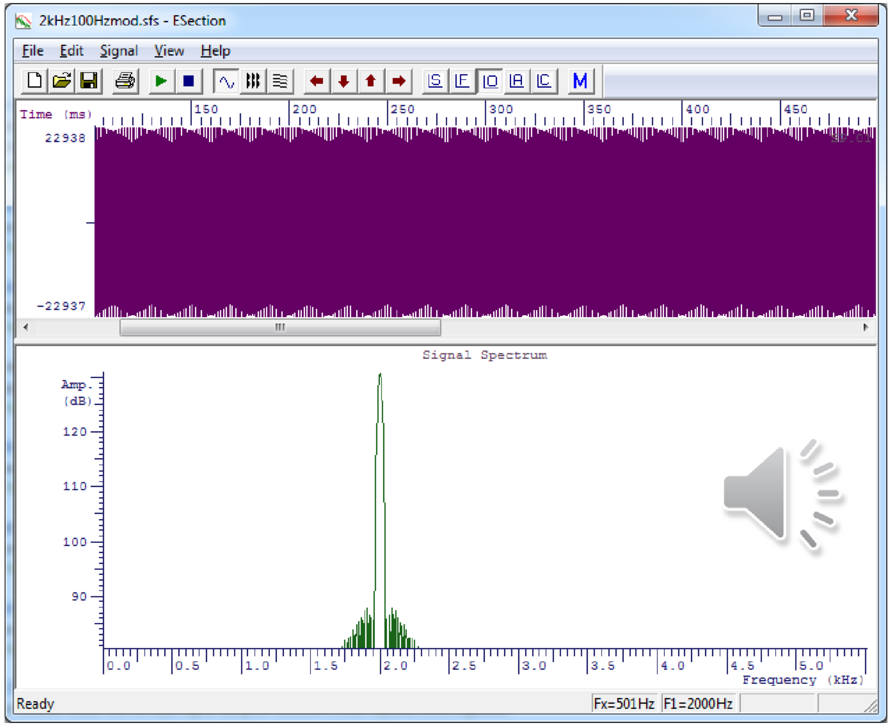
- Both involve *modulation* of the amplitude of waveforms …
  - Gap detection
  - Amplitude modulation
- But modulation almost always results in spectral changes.
- You usually cannot change the temporal (envelope) properties of a signal without also changing its spectrum
  - leading to uncertainty about what aspect of the sounds a listener is responding to

The need to eliminate spectral cues

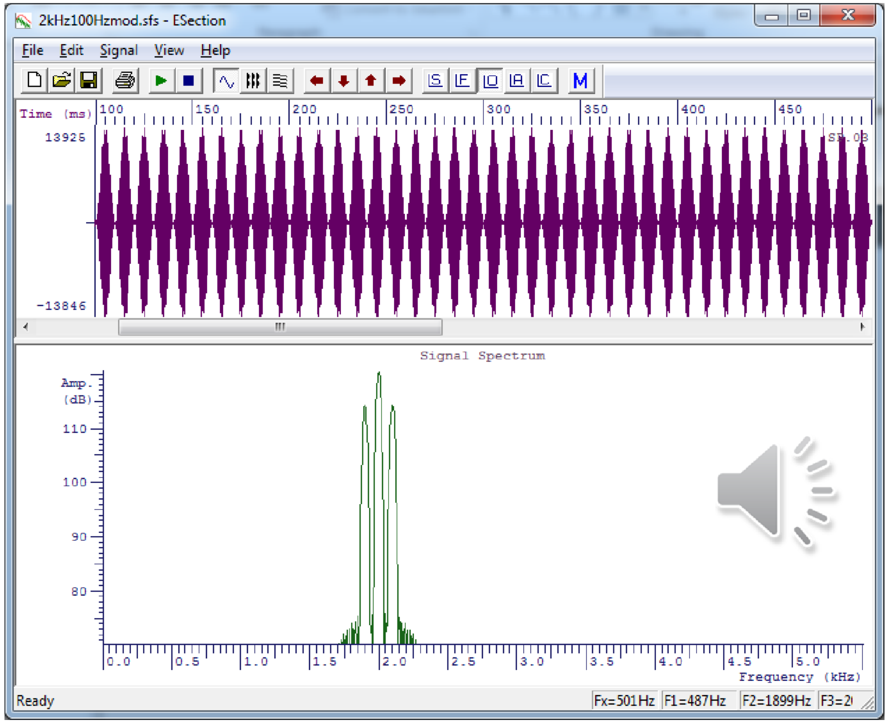
- Amplitude modulating signals usually results in spectral changes (broadening, known as *splatter*)
  - e.g., effect of 10 ms gap in spectrum of 1 kHz sinusoid
- Need to avoid listeners hearing spectral changes



Effects of amplitude modulation on the spectrum of a sinusoid



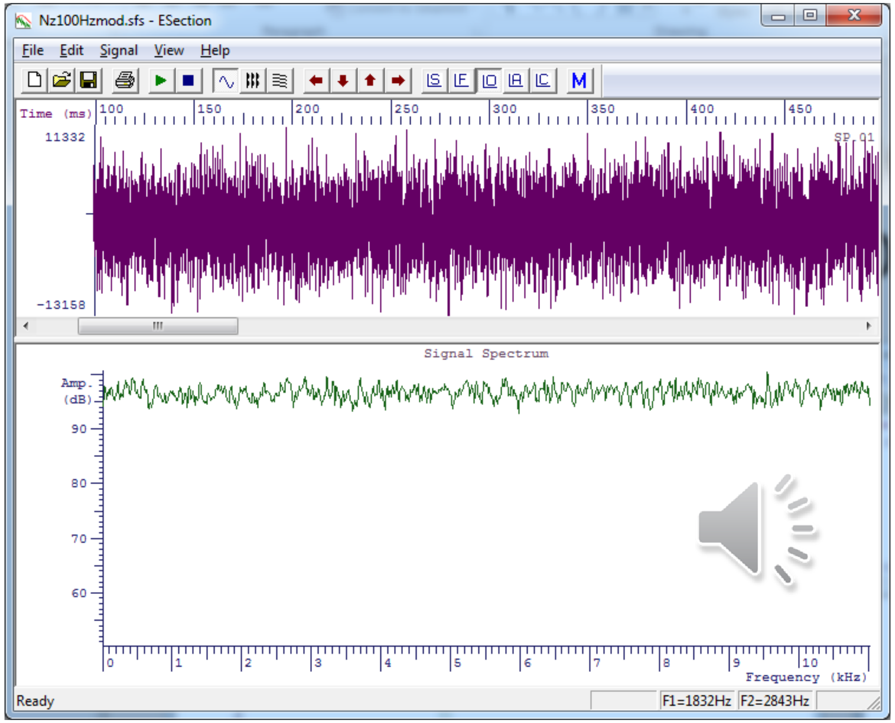
2 kHz sinusoid



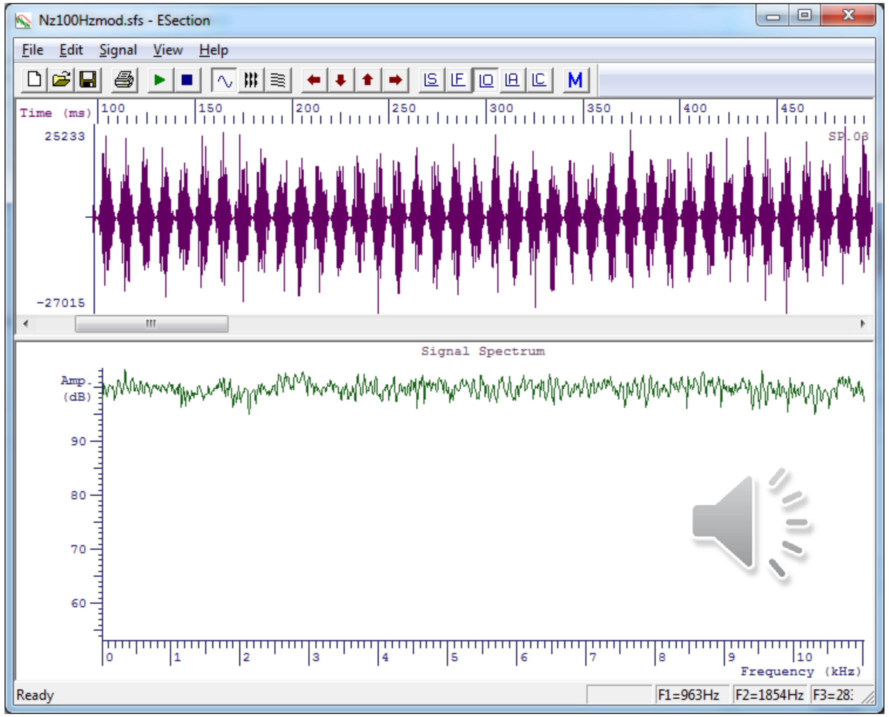
100 Hz AM of 2 kHz sinusoid

Spectral sidebands at 1900 and 2100 Hz

Effects of amplitude modulation on the spectrum of a white noise

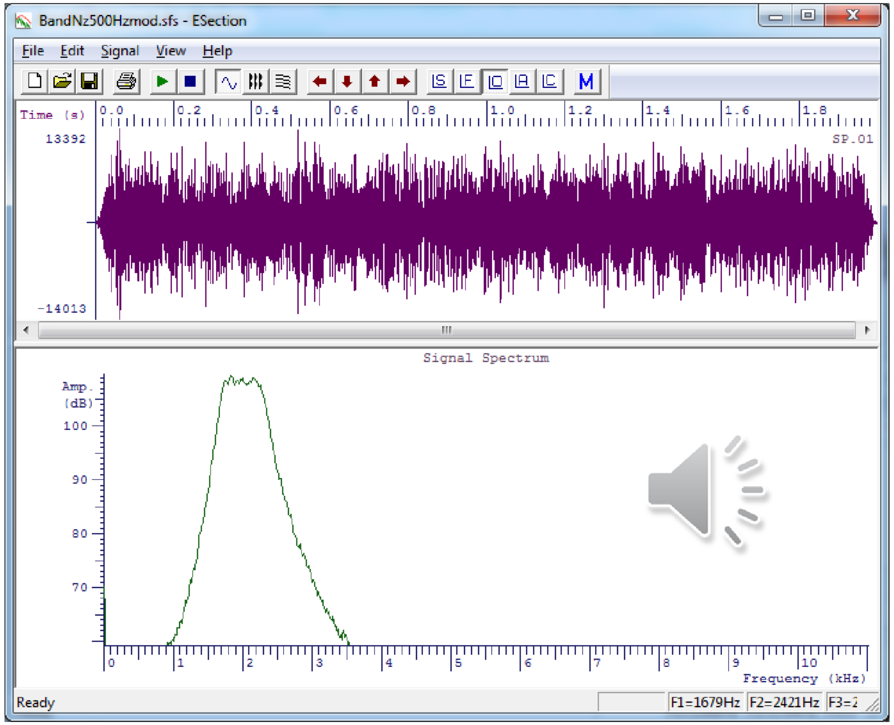


White noise

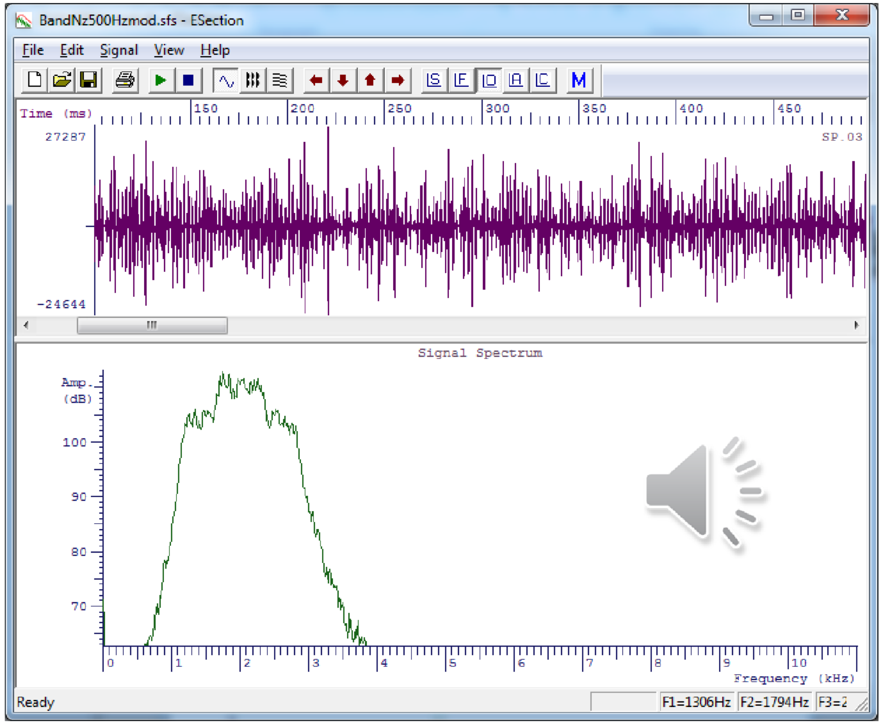


100 Hz AM of white noise

Effects of AM on the spectrum of a bandpass noise



bandpass noise



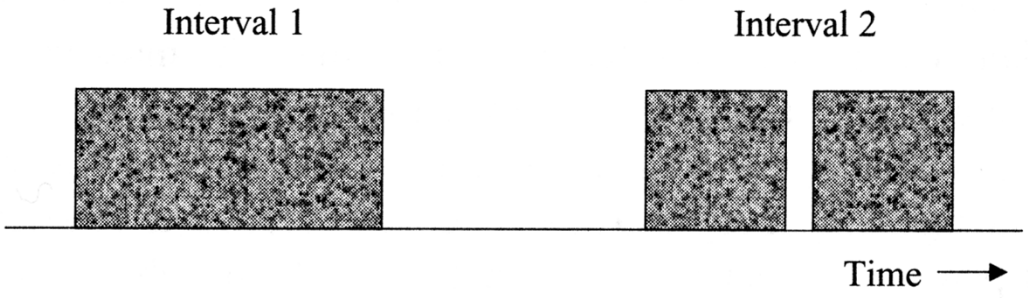
500 Hz AM of bandpass noise

Note the spectral sidebands, and that the perceived difference between the sounds is not temporal

Three ways to avoid the splatter problem

- Modulate wideband noise stimuli
- Minimise audibility of spectral changes by
  - keeping any sidebands in the same auditory filter as the original signal – allows use of low AM rates with sine carriers
  - and/or adding masking noise to make spectral changes inaudible
- Modulate wideband noise stimuli and filter into bands afterwards
  - but can change extent/form of modulation

Gap thresholds



- Pick the sound with the gap – vary the gap duration to find threshold
- Thresholds for wide-band noise are around 3 ms

Effects of noise spectrum on gap detection

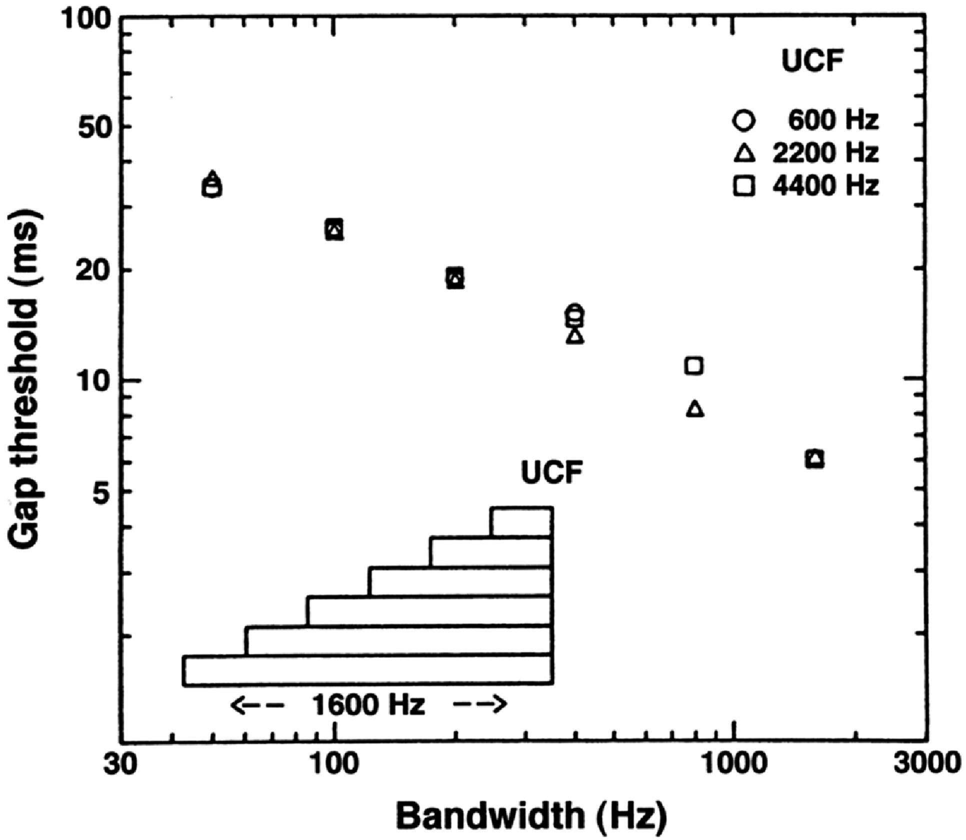


FIGURE 5.4 Gap thresholds for noise bands plotted as a function of the bandwidth of the noise bands. The upper cutoff frequency (UCF) of the noise bands was fixed at one of three values: 600, 2200, and 4400 Hz. The inset bars illustrate schematically how the bandwidth was varied keeping the UCF fixed. Gap thresholds decrease progressively with increasing bandwidth, but are almost independent of UCF. The data are from Eddins *et al*. (1992).

Wider noise bandwidth gives smaller gap thresholds

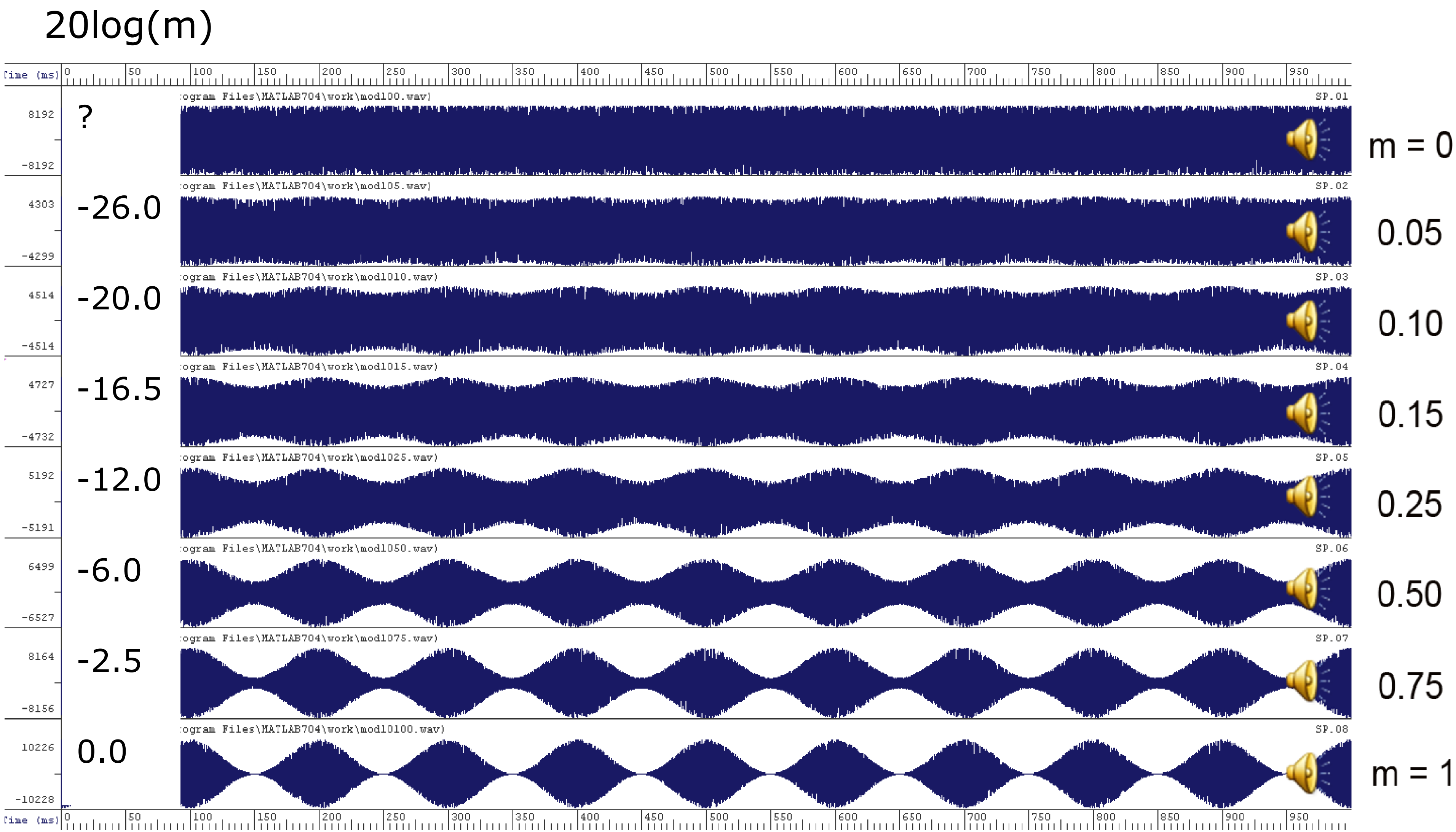
Frequency location of noise (UCF parameter) has little effect

May be because wide bandwidth allows listeners access to information from large numbers of filter channels

AM detection - TMTF

- TMTF – temporal modulation transfer function
- Analogous to an ordinary transfer function or frequency response
  - dealing with frequencies of *modulation* rather than frequencies of a sinusoidal waveform directly
- A more detailed approach to temporal resolution
  - Considers temporal modulation across different single frequencies of sinusoidal AM
    - cf gap detection where in effect the modulator is a pulse comprising wide range of modulation frequencies
  - As for gap thresholds, wide-band noise is an ideal signal because of the lack of spectral changes.
  - Fixed modulation rate – vary depth of modulation to determine minimum detectable depth

10 Hz modulation rate



Amplitude Modulation Detection

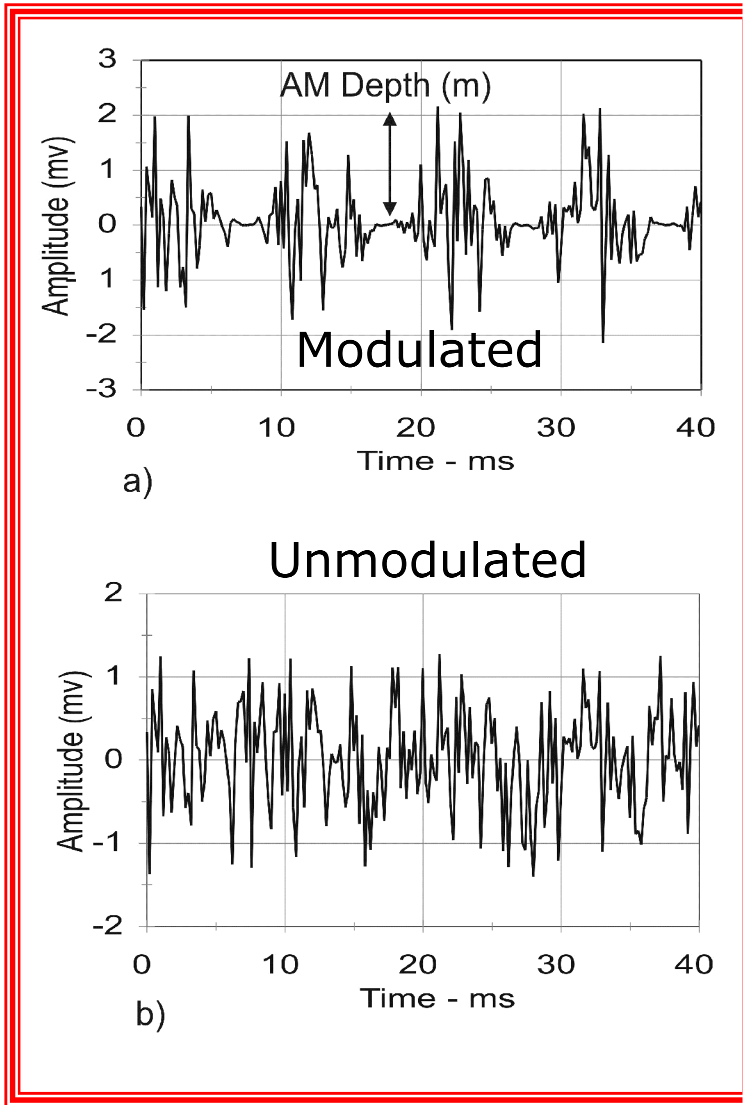
Four sets of amplitude modulated noises each of 500-msec duration with modulation rates of 4, 16, 64, and 256 Hz

For each set: ten comparisons of an unmodulated noise followed by the amplitude modulated noise

The depth of modulation starts at 50% or 20log(m) = -6 dB and decreases in 5% steps ending at 5%.

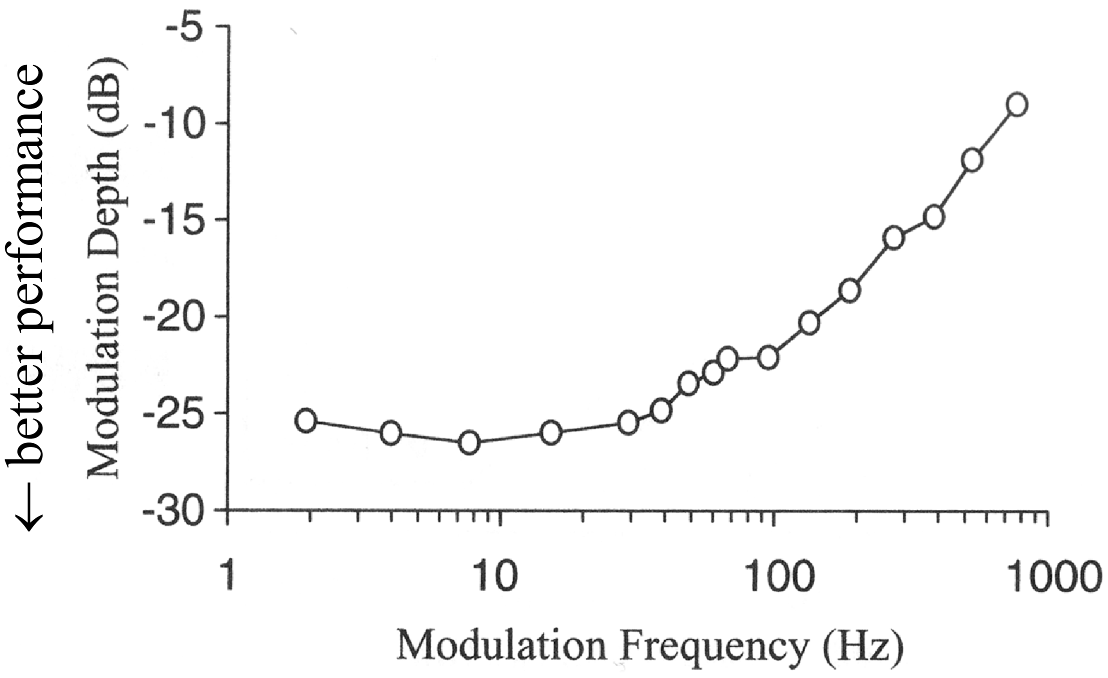
Count how many of the ten pairs have a noticeable modulation compared to the 1st unmodulated noise

4 Hz **16 Hz** **64 Hz** **256 Hz**



Results from a TMTF measurement

- Thresholds expressed in dB as 20 log(m) where m is modulation index

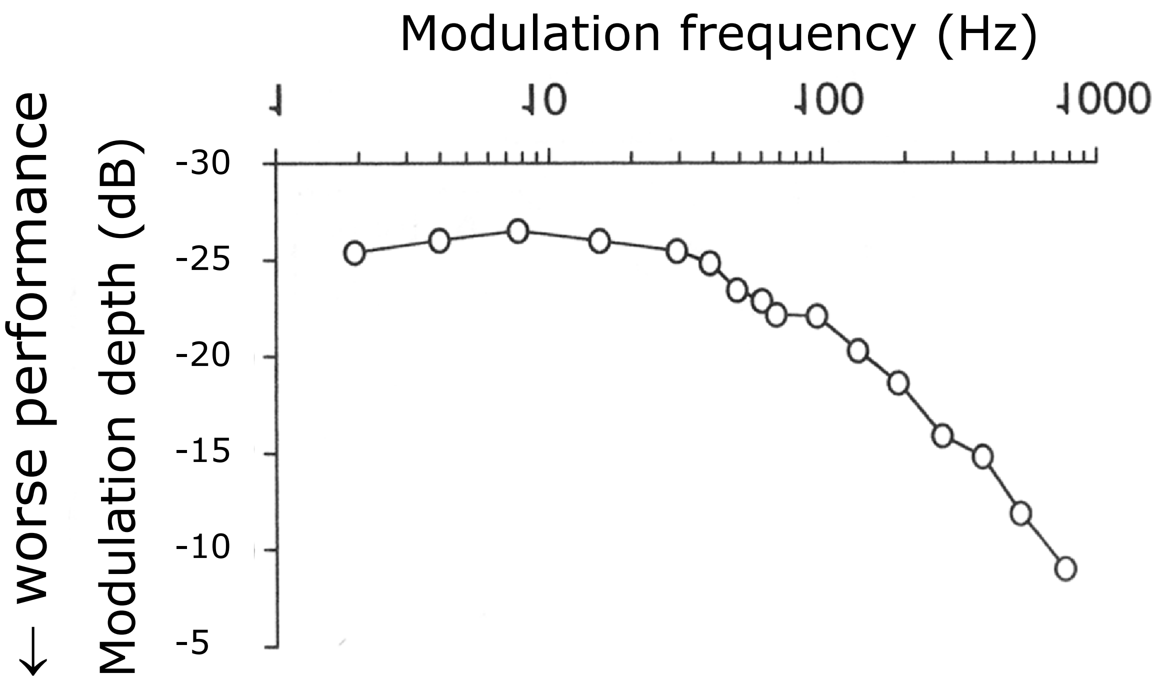


m = 1 gives 0 dB (modulation depth = carrier amplitude)

m = 0.05 gives -26 dB

Upper limit of amplitude modulation detection between 500 and 1000 Hz

Results from a TMTF measurement (inverted)



Remember: a transfer function is something like a frequency response. How well do the modulations get through?

What kind of modulation filter is this?

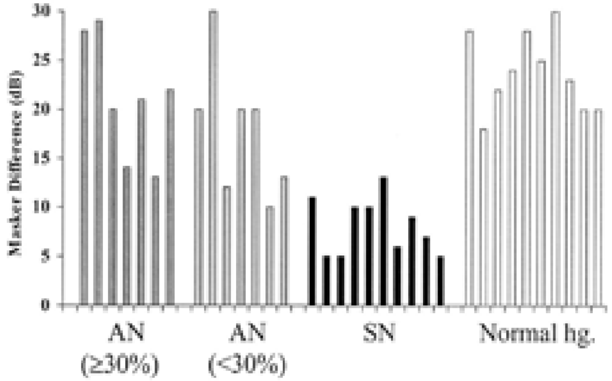
Translating to the clinic: Auditory Neuropathy Spectrum Disorder (ANSD)

Temporal resolution in ANSD

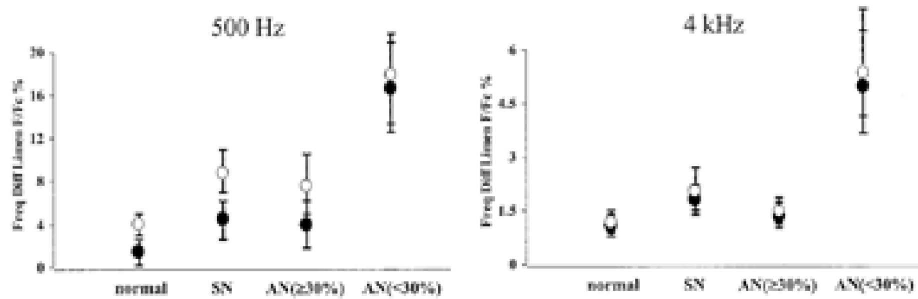
- ANSD defined by intact OHCs and normal OAEs but lack of CAP and ABR responses.
- Near normal audiometric thresholds but often severe problems with speech perception
- Problem in hair cell? Synapse? ???
- Likely to involve disruption of phase-locking in auditory nerve

Rance, McKay and Grayden, 2004 (Ear & Hearing)

- Compared children with normal hearing, SNHL, and ANSD
- Measured
  - Frequency selectivity (simple notched noise method)
  - Sinusoid frequency discrimination
  - TMTFs
  - CNC word phoneme recognition



SNR difference for thresholds in wide-band
and notched noise: 1 kHz probe, 500 Hz notch



Frequency discrimination thresholds
at 500 Hz and 4 kHz

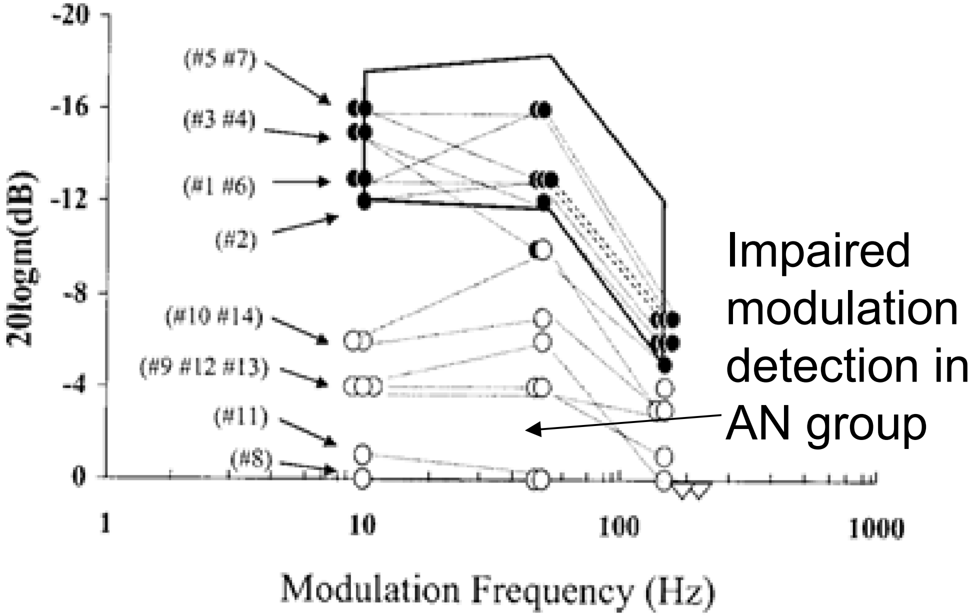


Figure 3. Amplitude modulation detection thresholds (AN subjects). Closed circles represent children in the AN ≥ 30% group, and open circles represent the children in the AN < 30% group. Open triangles show the findings for children in the AN < 30% group unable to detect a modulation depth of 0 dB. The enclosed area shows the mean ±2 SD range for the normal-hearing group.

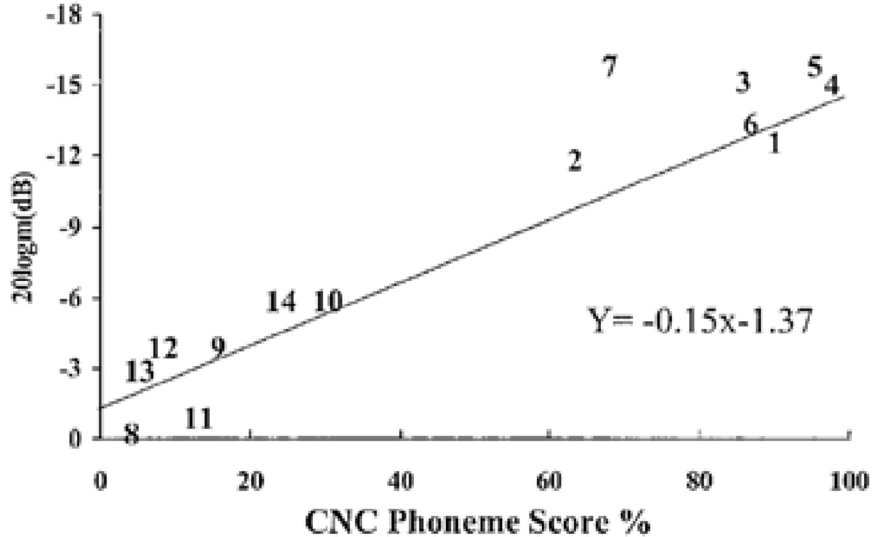


Figure 4. Amplitude modulation detection threshold (10 Hz MF) plotted as a function of CNC phoneme score (AN subjects). The data point for each child is represented by the subject identification number.

Temporal resolution and temporal frequency coding seems impaired in ANSD

- And both correlate highly with speech scores
- While auditory filtering seems near-normal in many of the ANSD subjects

A model of temporal resolution – the temporal window

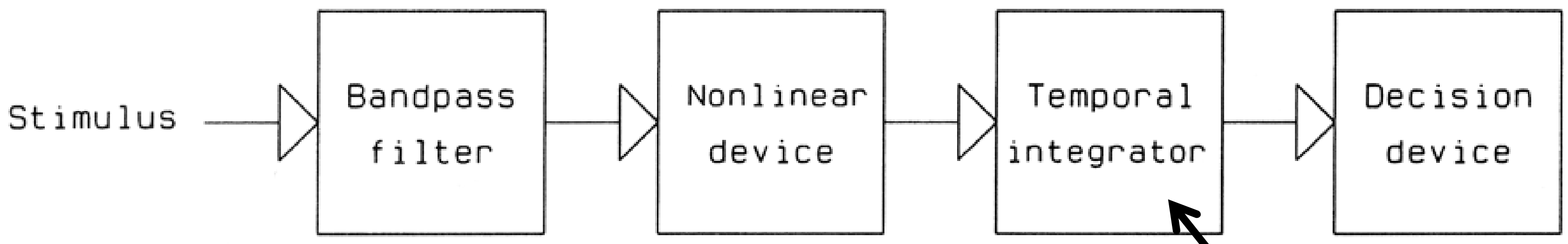


FIGURE 5.9 A block diagram of a model of temporal resolution.

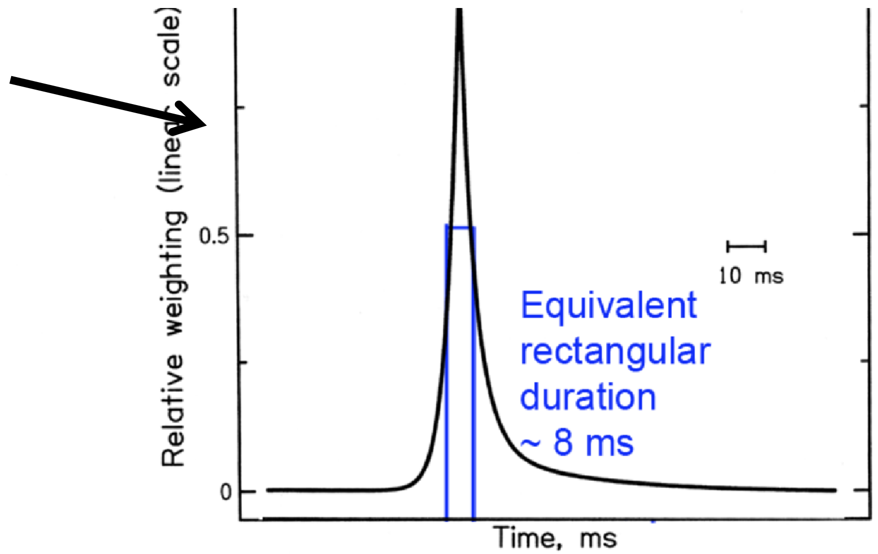
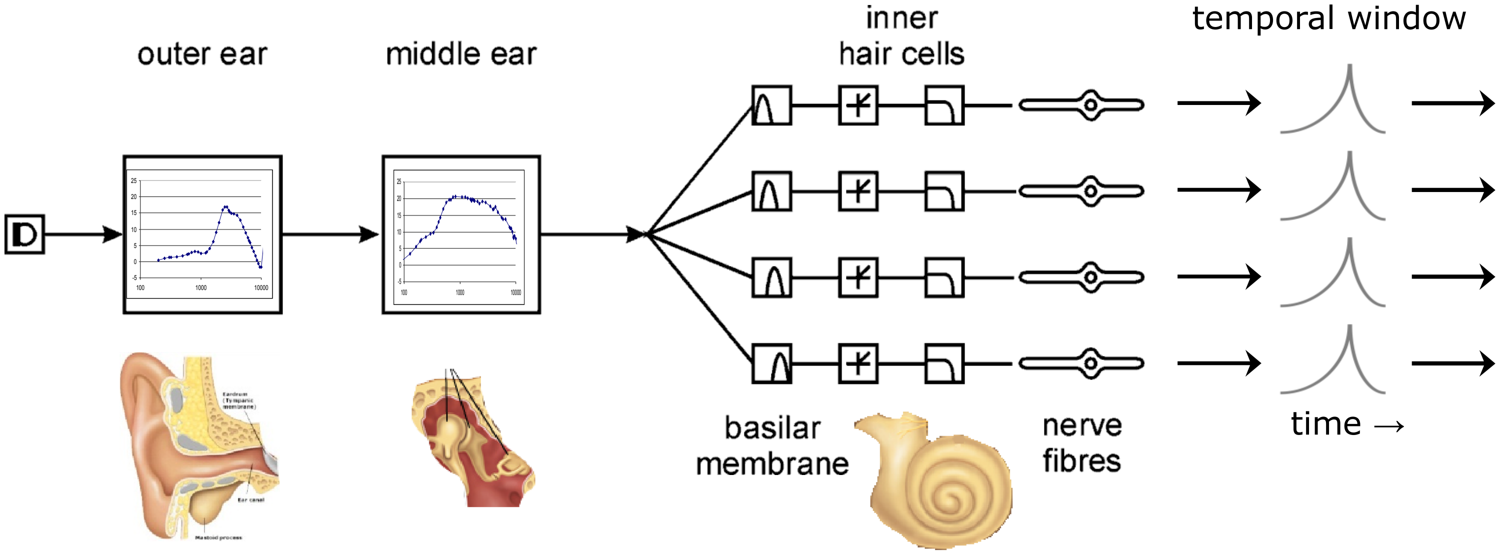


FIGURE 5.10 The "shape" of the sliding temporal integrator (window). This is a weighting function applied to the output of the nonlinear device. It performs a weighted running average of the output of the nonlinear device. The shape is plotted on a linear scale as a function of time.

LTI system characterised by a frequency response

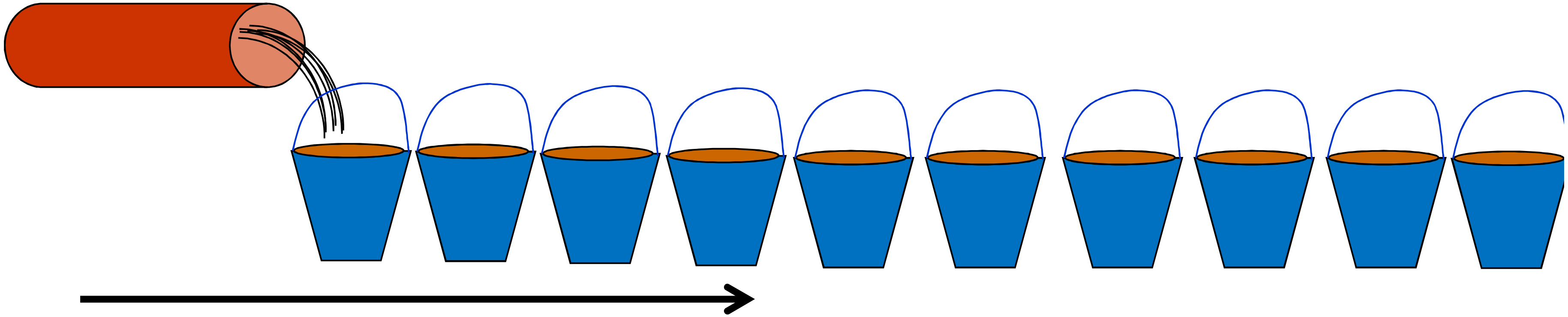
or … ?

A model of the auditory periphery



Hydraulic analogy: How long before the next bucket leaves for the brain?

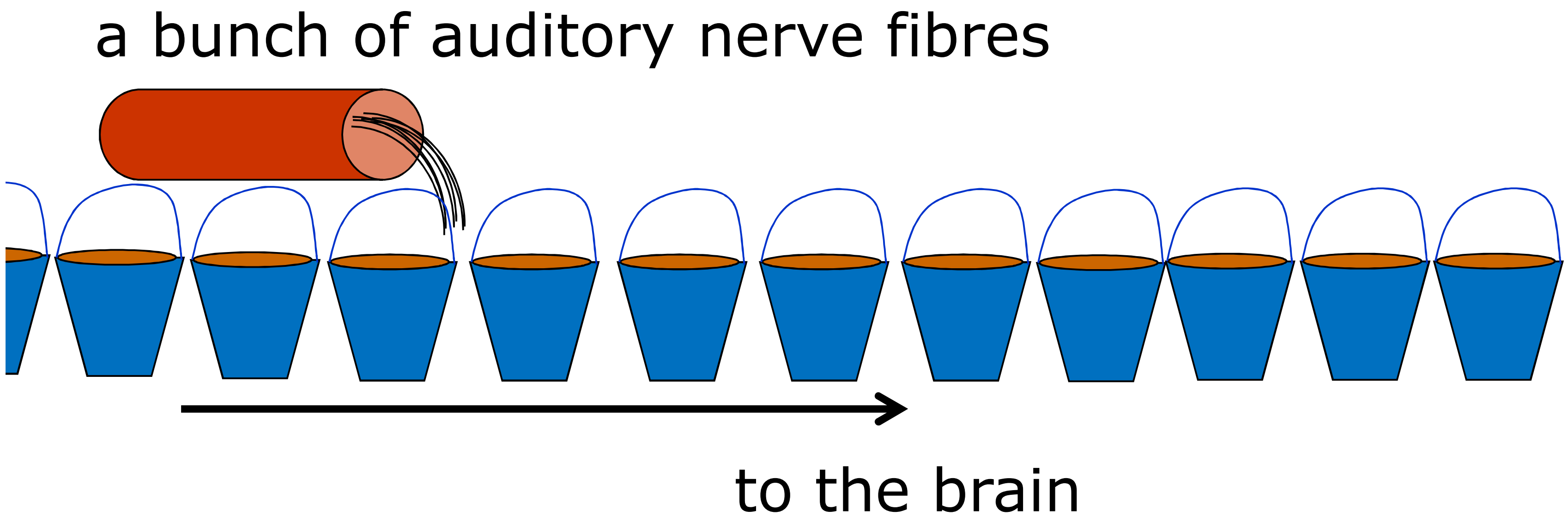
a bunch of auditory nerve fibres



to the brain

slow modulations

Hydraulic analogy: How long before the next bucket leaves for the brain?



rapid modulations

(slides modified from Lynne Werner, U of Washington, Seattle)

A model of temporal resolution – the temporal window

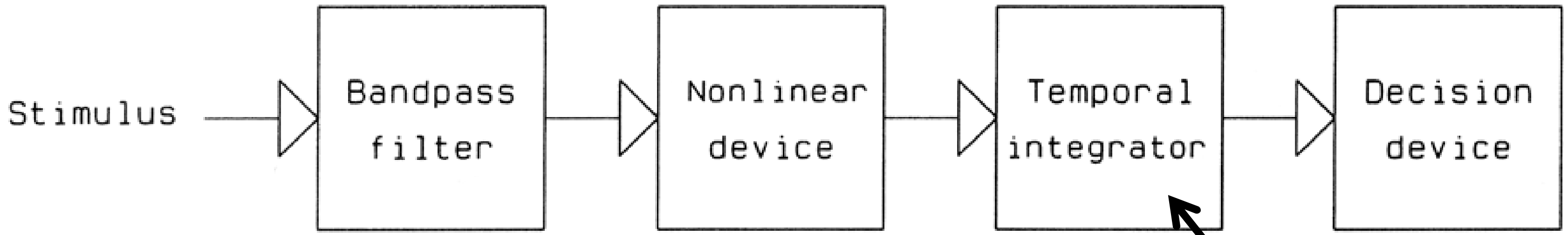


FIGURE 5.9 A block diagram of a model of temporal resolution.

LTI system characterised by a frequency response

or … ?

An impulse response

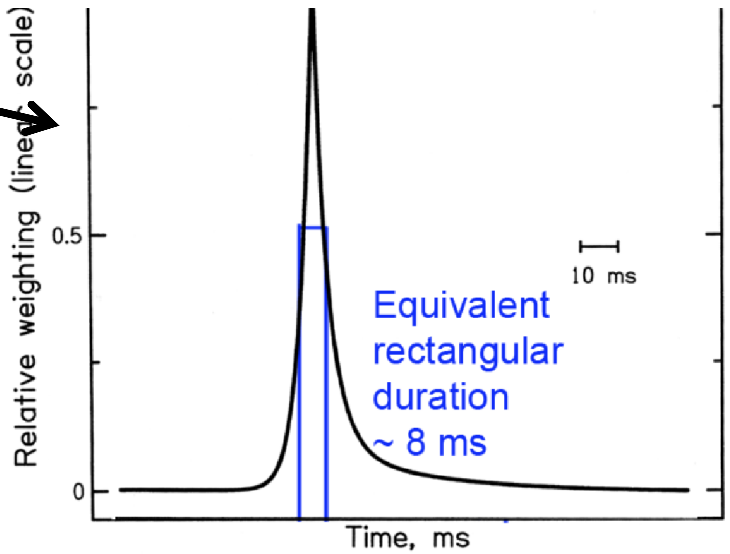
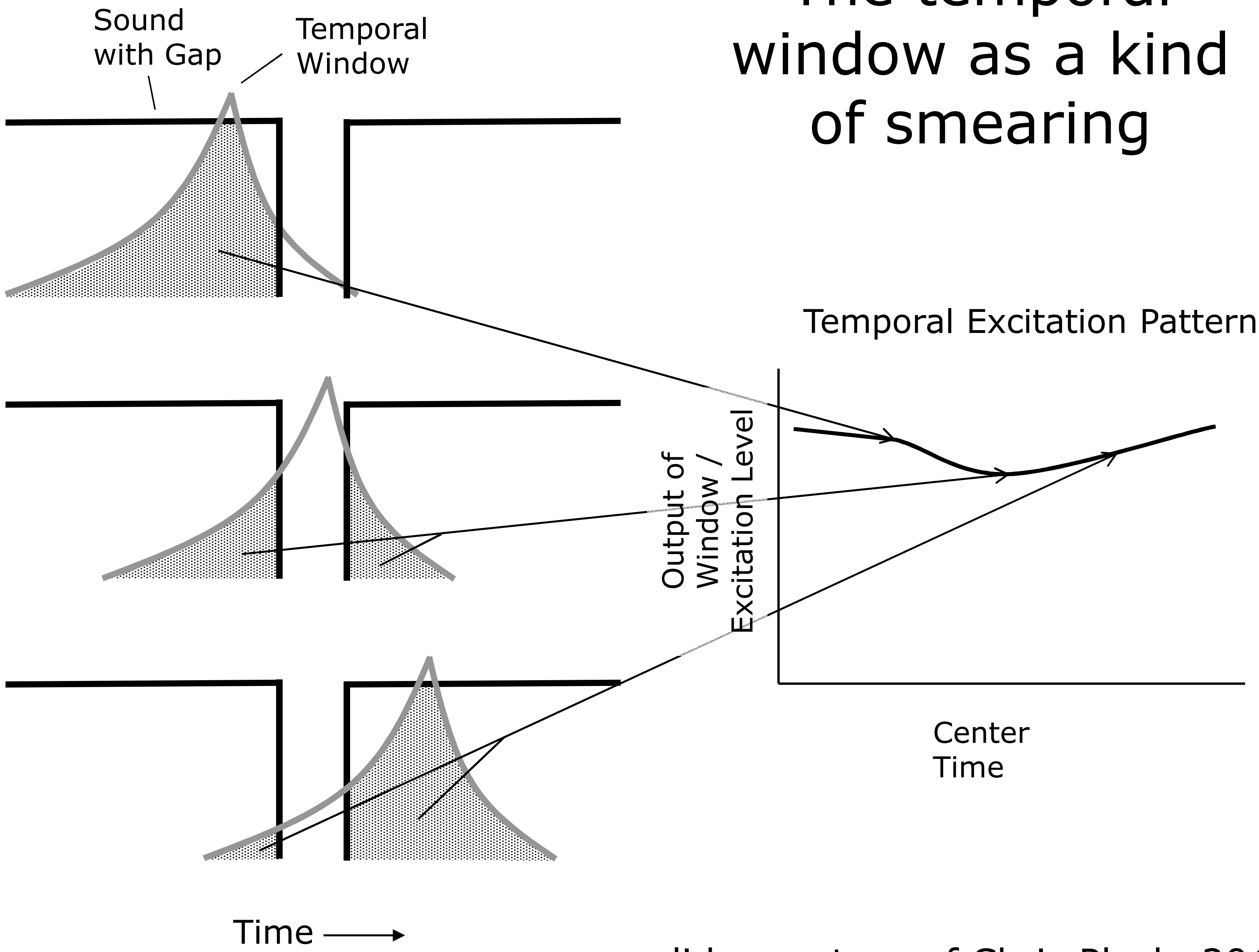


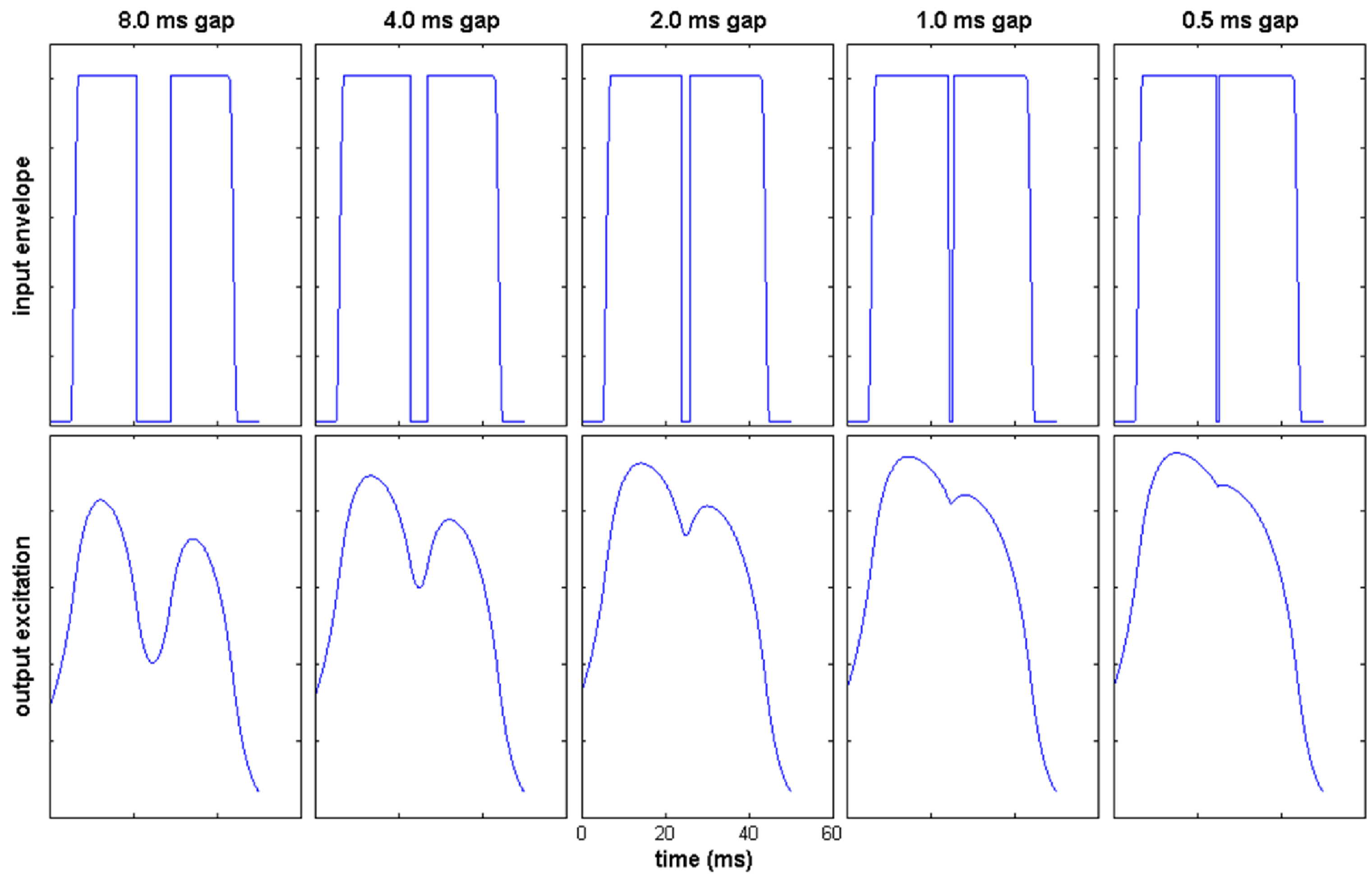
FIGURE 5.10 The "shape" of the sliding temporal integrator (window). This is a weighting function applied to the output of the nonlinear device. It performs a weighted running average of the output of the nonlinear device. The shape is plotted on a linear scale as a function of time.

The temporal window as a kind of smearing



slide courtesy of Chris Plack, 2013

gap detection seen through the temporal window model



Effects of temporal window on signals

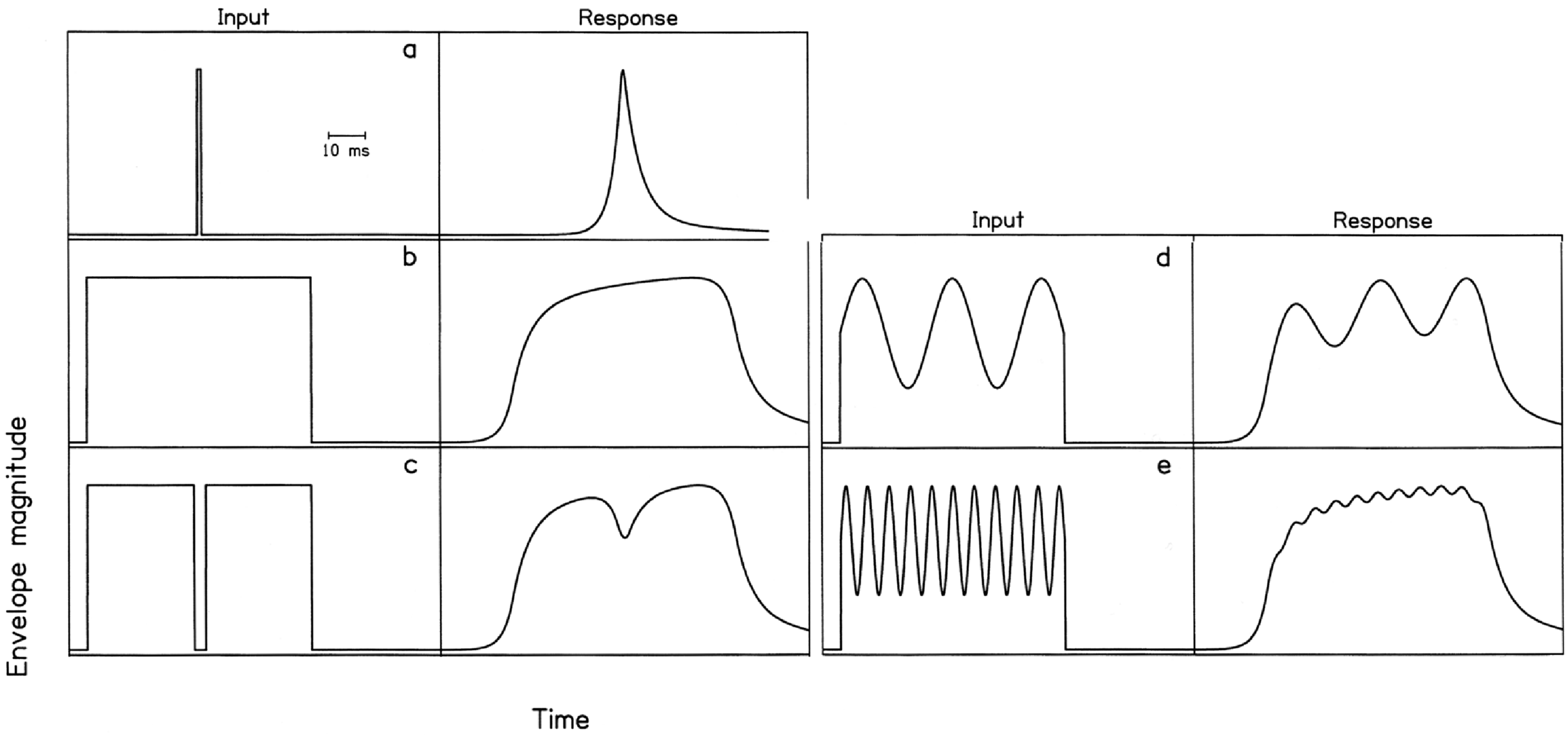
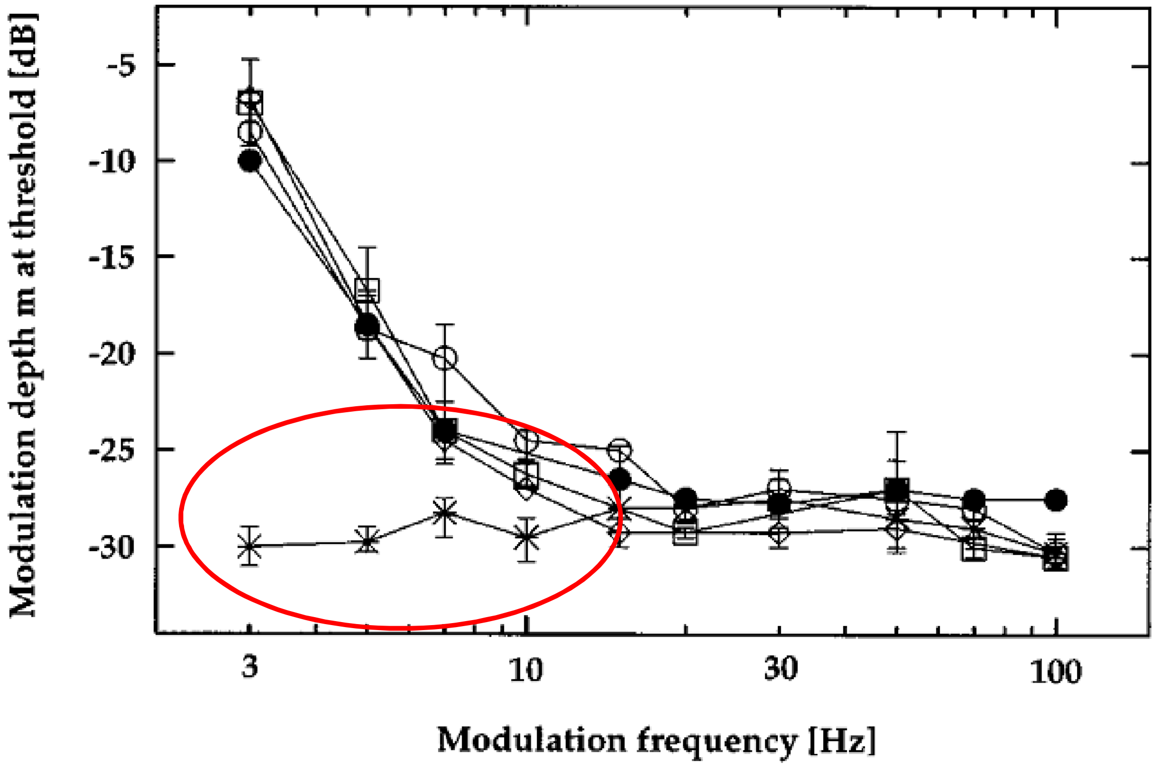


FIGURE 5.11 Examples of the influence of the sliding temporal integrator on the envelopes of sounds. The panels on the left show inputs to the sliding temporal integrator. The panels on the right show the corresponding outputs.

Decision device looks at evidence of level changes at output – a model of *within-channel* temporal resolution

But this model can't be right!



Modulations in the stimulus matter as well

FIG. 3. Modulation-detection thresholds of sinusoidal amplitude modulation as a function of the modulation frequency. The carrier was a 3-Hz-wide running noise at a center frequency of 5 kHz. Carrier and modulation duration: 1 s. Level: 65 dB SPL. Subjects: JV (□); AS (◇); TD (○); optimal detector (●). In addition, the modulation detection thresholds of one subject (TD) for a 5-kHz sinusoidal carrier are indicated by (⋆).

Dau, T., Kollmeier, B., & Kohlrausch, A. (1997). Modeling auditory processing of amplitude modulation 1. Detection and masking with narrow-band carriers. *J Acoust Soc America, 102,* 2892-2905.

A modulation filter bank

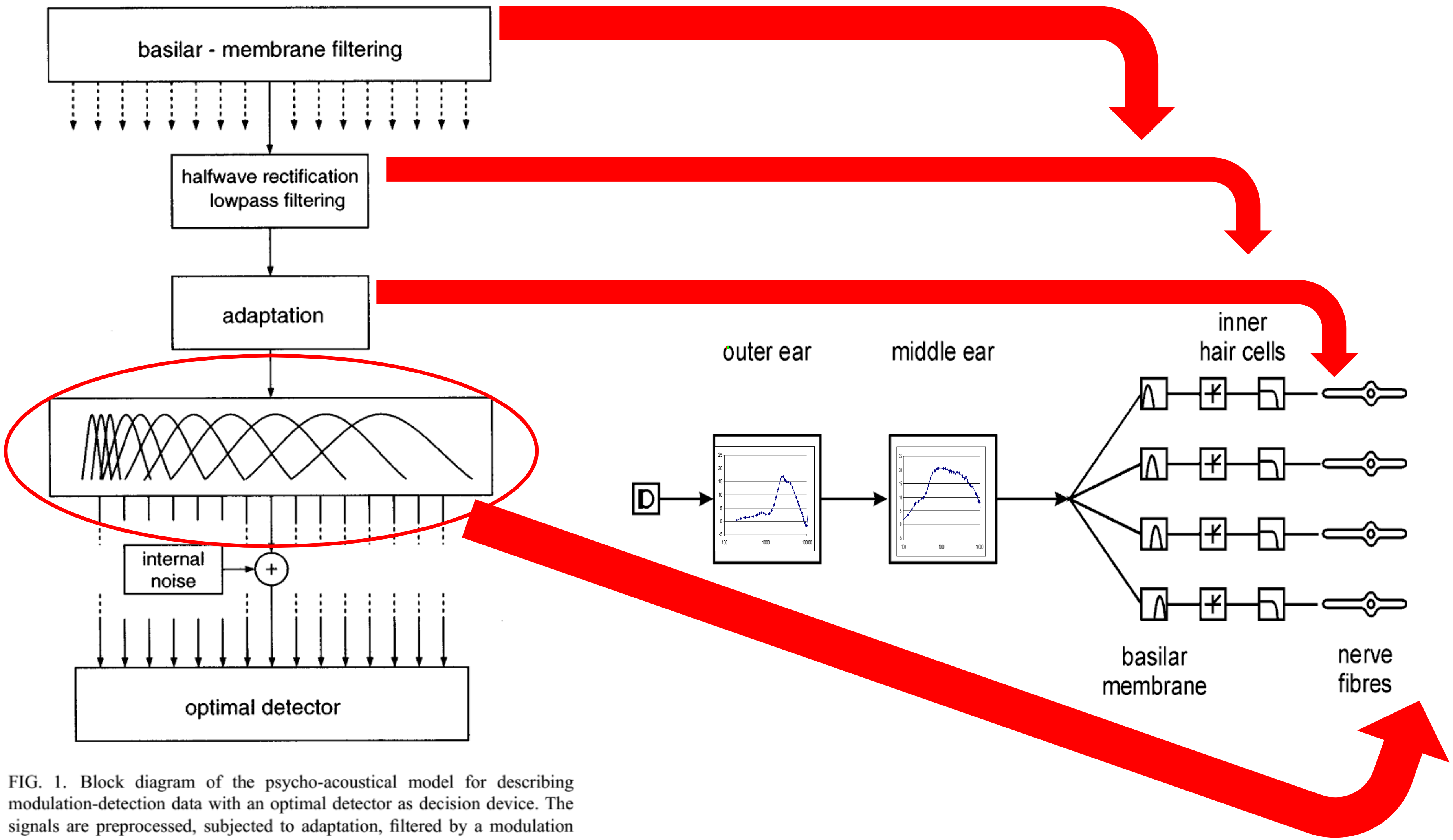
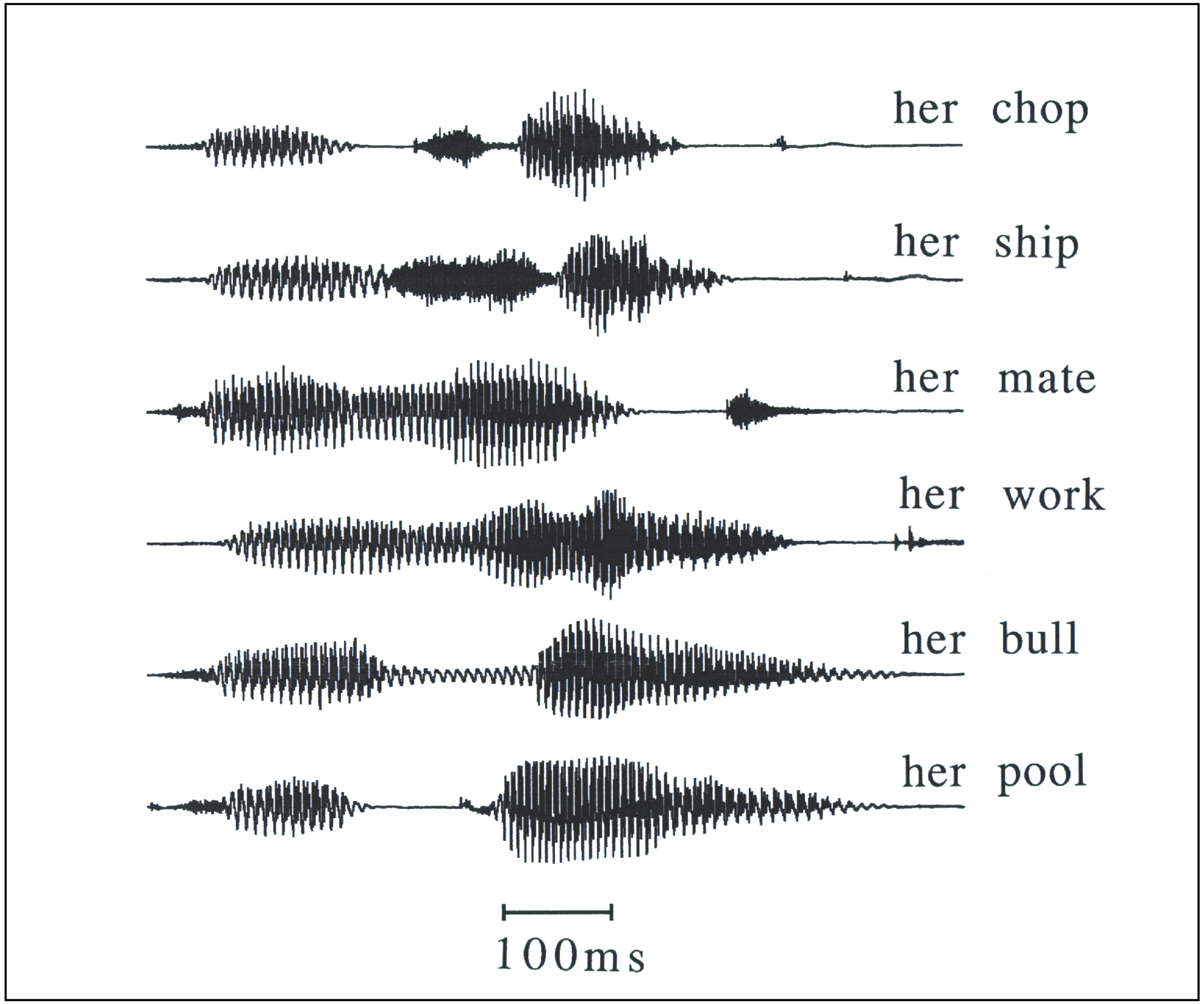
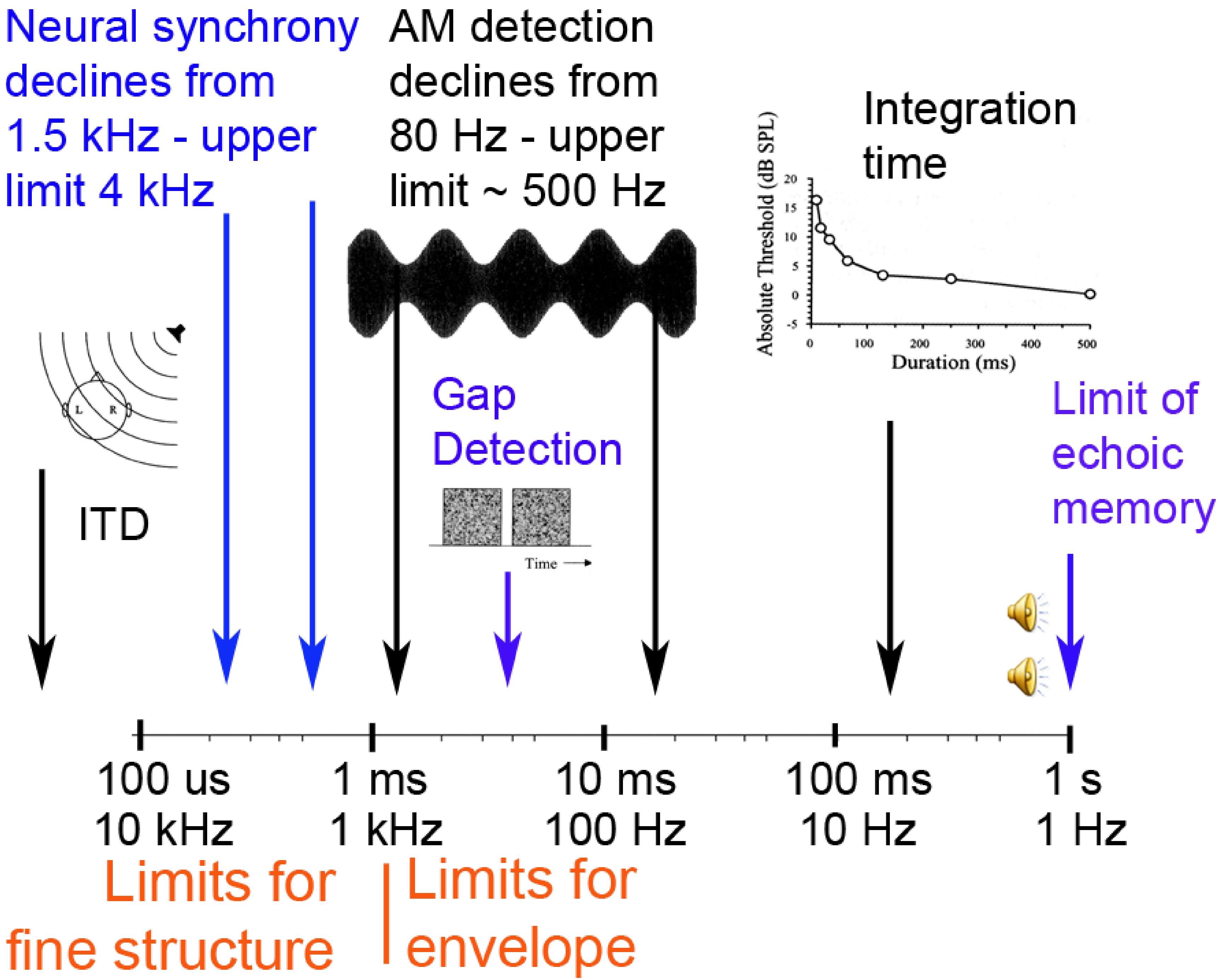


FIG. 1. Block diagram of the psycho-acoustical model for describing modulation-detection data with an optimal detector as decision device. The signals are preprocessed, subjected to adaptation, filtered by a modulation filterbank and finally added to internal noise; this processing transforms the signals into their internal representations.

Envelope in speech – one source of cues to consonants





Neural synchrony declines from 1.5 kHz - upper limit 4 kHz
AM detection declines from 80 Hz - upper limit ~ 500 Hz
Integration time
Absolute Threshold (dB SPL)
Duration (ms)
0
100
200
300
400
500
20
15
10
5
0
-5
L
R
ITD
Gap Detection
Time
Limit of echoic memory
100 us
10 kHz
1 ms
1 kHz
10 ms
100 Hz
100 ms
10 Hz
1 s
1 Hz
Limits for fine structure
Limits for envelope

Key Points

- Measures of temporal resolution relate to signal envelopes
- Measures must control spectral artefacts
- Gap detection and TMTF main measures
  - Both indicate limits in region of 1 to 3 ms in normal hearing
- Temporal window model can account reasonably well for within-channel temporal resolution