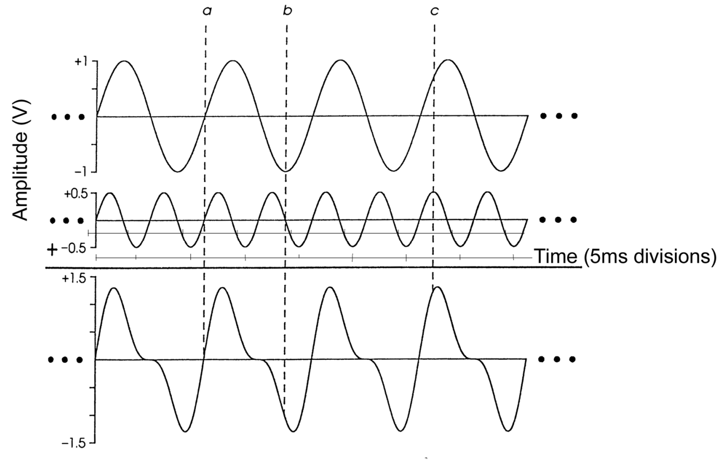
AUDL 4007
Auditory Perception

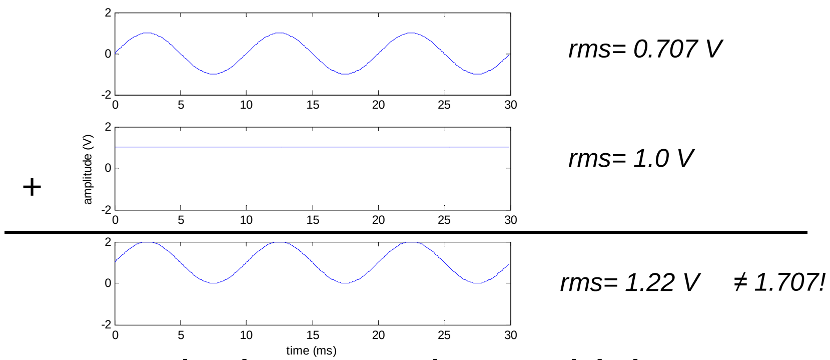
Week 2

Mathematical prelude: Adding up levels

You know about adding up waves, e.g. from two loudspeakers



But how do you get the total rms from the rms values of two signals that are added?



rms= 0.707 V

rms= 1.0 V

rms= 1.22 V ≠ *1.707!*

Conclusion: you don't add them!
(the squaring for rms is non-linear)

Powers & intensities *do* add

power/intensity ~ voltage²/pressure²

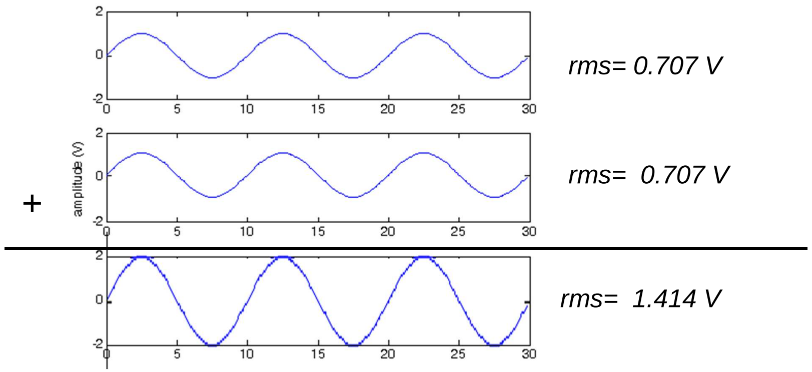
no need to worry about constant of proportionality

$$\sqrt{0.7072^2 + 1^2} = \sqrt{0.5+1.0} = \sqrt{1.5} = 1.22$$

This holds true as long as the two signals *do not overlap in spectrum*

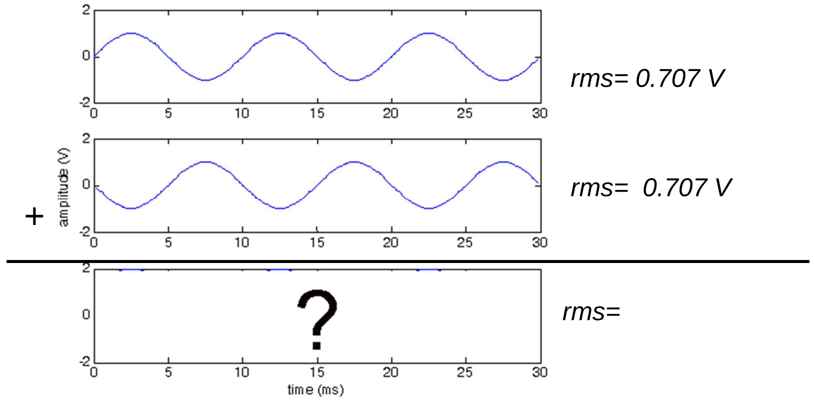
What can happen when you add a 1-V 1-kHz sine wave to another 1-V 1-kHz sinusoid?

Add two 1-V 1kHz sine waves



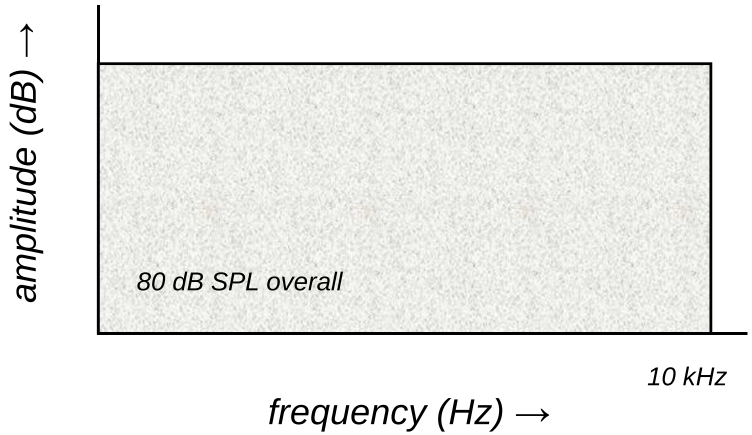
Powers do not add – rms (and peak) voltages add

BUT ------------ two 1-V 1kHz sine waves

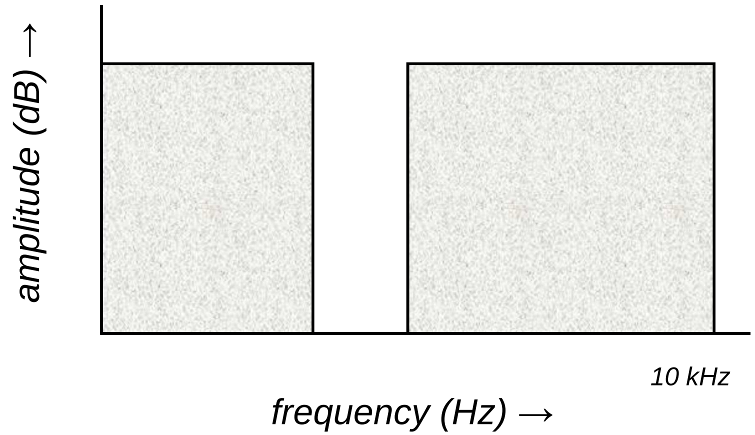


For same frequency signals, result depends on relative phase: you can't add powers

Specifying levels for noises: signals with *continuous* spectra



Specifying levels for noises: signals with *continuous* spectra



40 dB SPL spectrum level

Specifying levels for noises signals with *continuous* spectra

- spectrum level
  - measured within a 1 Hz band
- overall level
  - summed over the whole spectrum
- converting between measures has to be done in terms of *power*, not amplitude.

Converting between measures

- Suppose the spectrum level of noise was 40 dB SPL
  - measured within a 1 Hz band
- What would be the overall level of a noise ranging from 100 - 1100 Hz?
- Convert 40 dB SPL to intensity, then add together 1000 times (multiply by 1000)
- overall = spectrum level + 10 log(BW)
  - here, 40 + 10 log(1000) = ?
- spectrum level = overall - 10 log(BW)

Interlude: signal-to-noise ratio (SNR)

- Literally …
  - rms level of signal/rms level of noise
- usually expressed in dB
  - $20 \log_{10}(\text{signal/noise})$
- Nothing implied about the form of the signal or noise
  - the signal is what you are interested in (*e.g.,* a tone, a band of noise, a word, a sentence)
  - the noise is everything else (*e.g.,* a tone, car noise, speech from other people)

Various SNRs for a sentence in speech-shaped noise

SNR of +40 dB?
SNR of -40 dB?
SNR of 0 dB?

Intelligibility for a particular SNR depends on many factors

SNR of -10 dB for speech-shaped noise

SNR of -10 dB for a single male talker in the background

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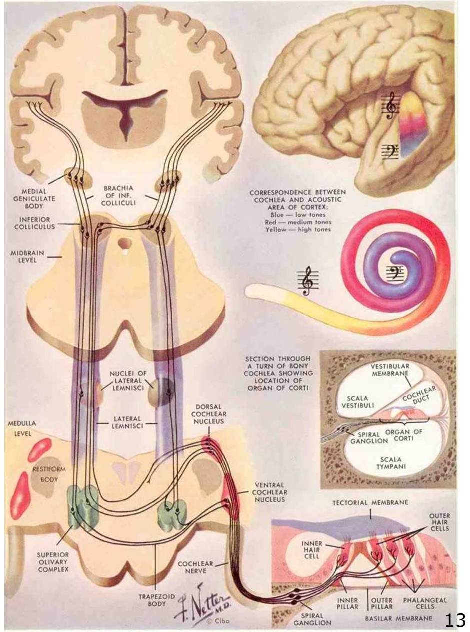
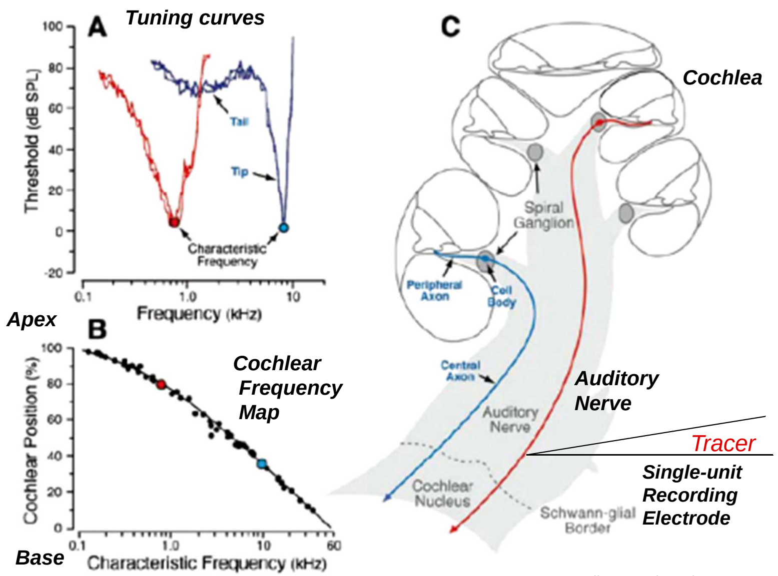
Psychoacoustic
reflections of
frequency
selectivity

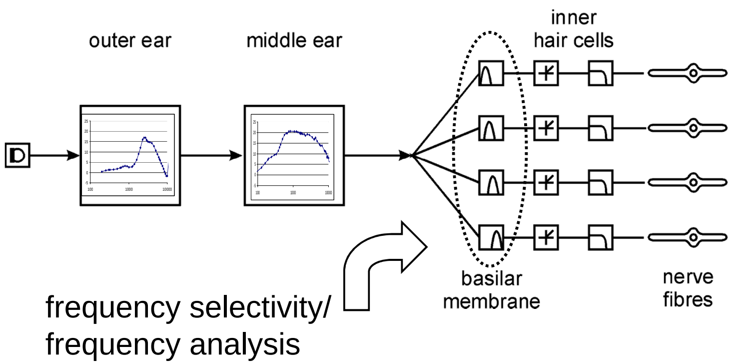


Auditory Nerve Structure and Function



Liberman (1982)

The auditory periphery as a signal processor



auditory filters & channels

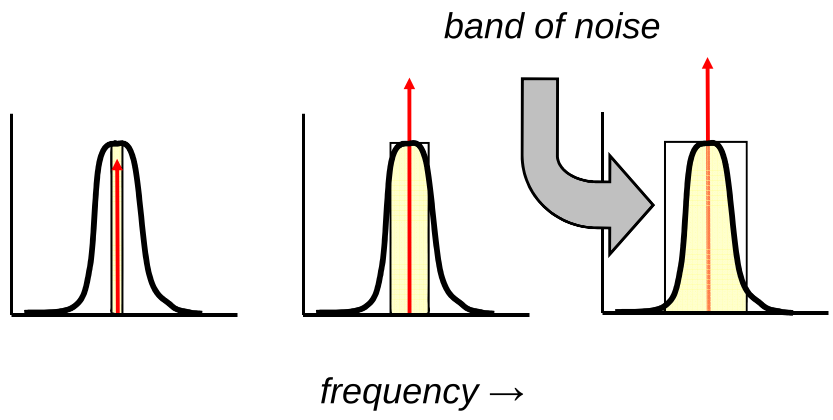
Masking experiments

- Listen for a probe (typically a sinusoid) in a background of a masker with a variety of spectral shapes (typically a noise).
- Assume: A listener has independent access to, and can 'listen' selectively to the output of an individual auditory filter – the one that will give best performance.
  - *the probe frequency controls the centre frequency of the auditory filter that is attended to*
- Assume: Only noise that passes through the same filter as the sinusoid can mask it.
- Assume: Only the 'place' principle applies — no temporal information.
- The *power spectrum model of masking*

The frequency specificity of masking

- Listen for a set of three pulsing tones (the *signal* or *probe*).
- These will alternate with masking noises that occur twice each, and change through the series.
- If two masking noises in a row sound identical, then you can't hear the probe tone — it has been *masked.*
- When is the tone masked, and when not?

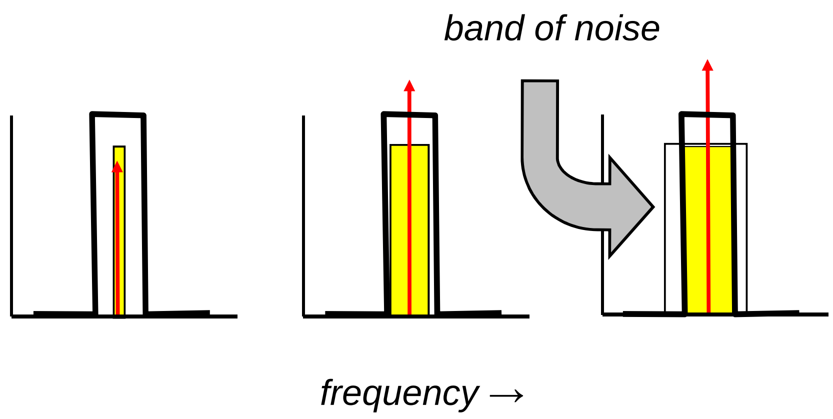
Of mostly historical interest: Band-widening



The band-widening experiment

- Measure the threshold of a sinusoid in the centre of a band of noise
- Vary the width of the band of noise
- Assuming auditory filters can be thought of as ideal bandpass filters, how should the thresholds for the probe change as bandwidth increases?

Simplify by assuming an ideal (rectangular) auditory filter



The notion of the *critical band* as seen in band-widening experiments

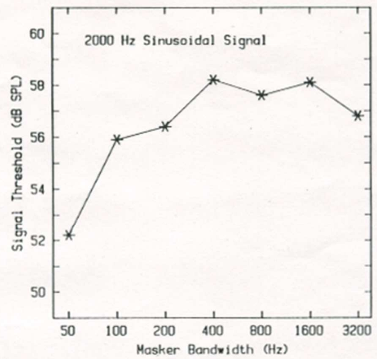
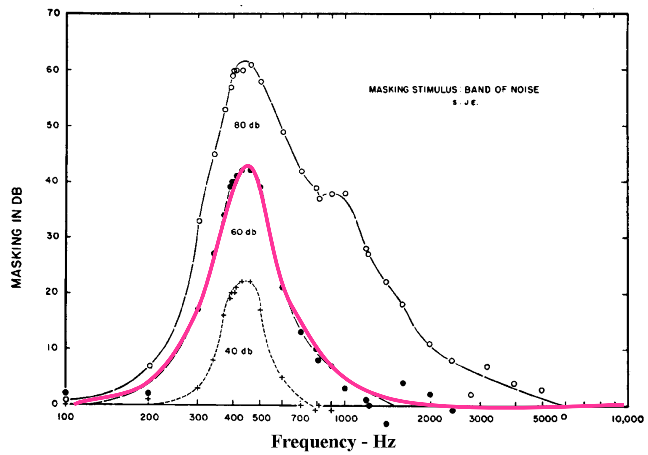


FIG. 3.1 The threshold of a 2000 Hz sinusoidal signal plotted as a function of the bandwidth of a noise masker centred at 2000 Hz. Notice that the threshold of the signal at first increases with increasing masker bandwidth and then remains constant. From Schooneveldt and Moore (1989).

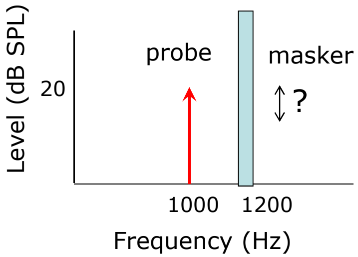
The masked audiogram

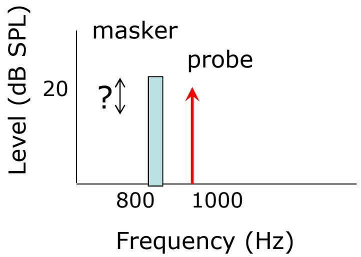
For a fixed narrow-band masker, determine the change in threshold for sinusoidal probes at a wide variety of frequencies.

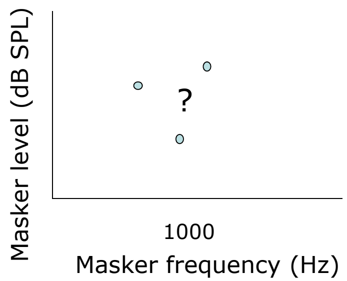


Excitation pattern (spectrum) or tuning curve (frequency response)?

Psychophysical tuning curves (PTCs)

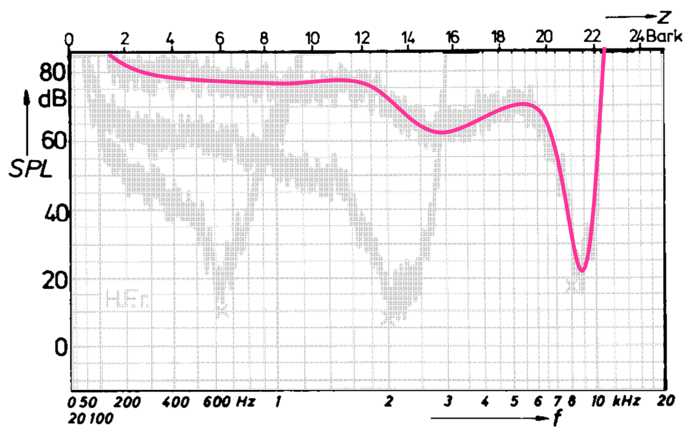






Psychophysical tuning curves (PTCs)

Determine the minimum level of a narrow-band masker at a wide variety of frequencies that will just mask a fixed ***low-level*** *sinusoidal probe.*



Why low level?

Excitation pattern (spectrum) or tuning curve (frequency response)?

Why you can't easily interpret PTCs at higher levels: Off-frequency/ place listening

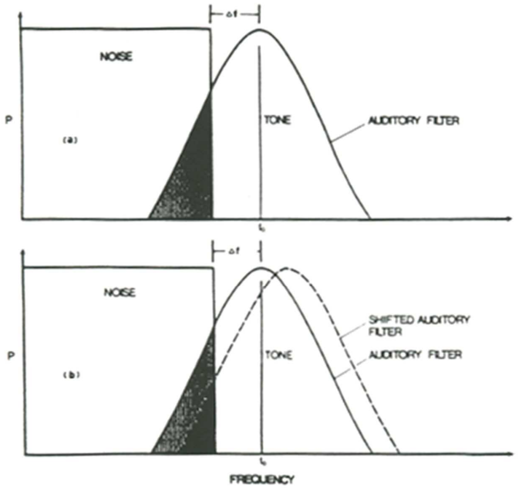


Figure 10.8 In both graphs, the solid curve represents the auditory filter centered at the test tone and the square at the left portrays a lower frequency masking noise. Off-frequency listening occurs when the subject shifts to another auditory filter (indicated by the dashed curve in graph b) in order to detect the presence of a test signal. (Adapted from Patterson [33], with permission of J. Acoust. Soc. Am.)

From Gelfand (1998)

Notch (*band stop*) noises limit off-place listening

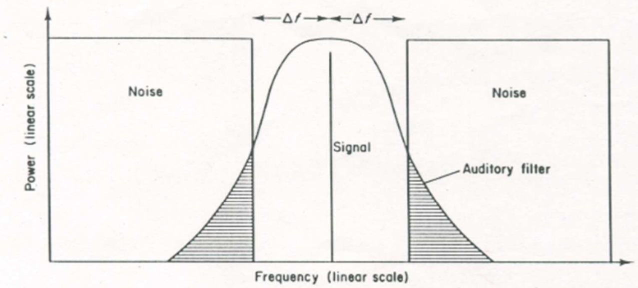
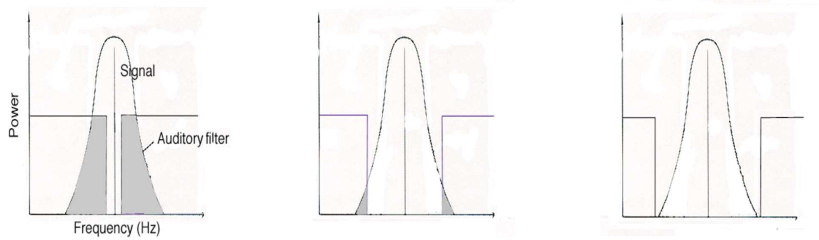


FIG. 3.6 Schematic illustration of the technique used by Patterson (1976) to determine the shape of the auditory filter. The threshold of the sinusoidal signal is measured as a function of the width of a spectral notch in the noise masker. The amount of noise passing through the auditory filter centred at the signal frequency is proportional to the shaded areas.

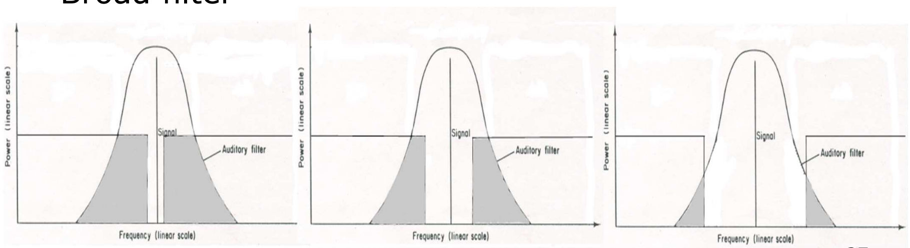
From Moore (1997)

Narrow vs broad filters

Narrow filter

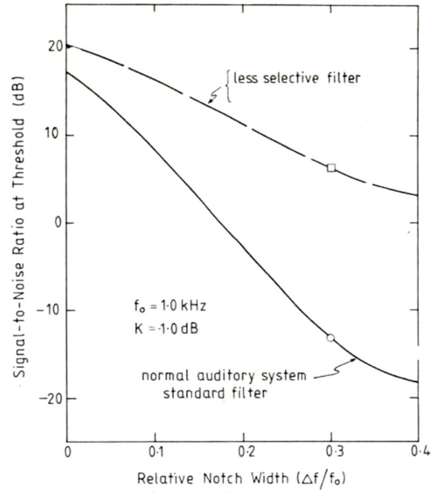


Broad filter



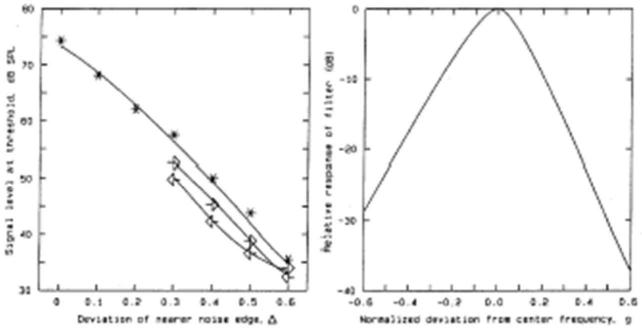
Notch gets wider →

Thresholds at different notch widths



From Patterson et al. (1982)

Typical results at one level, and a fitted auditory filter shape (symmetric & asymmetric notches)



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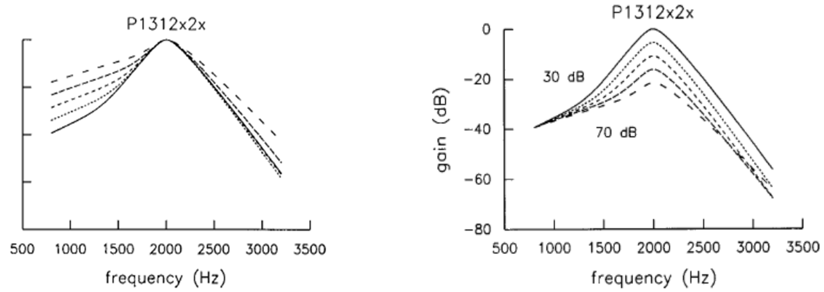
Now measure across level and assume filter linearity at frequencies substantially lower than CF



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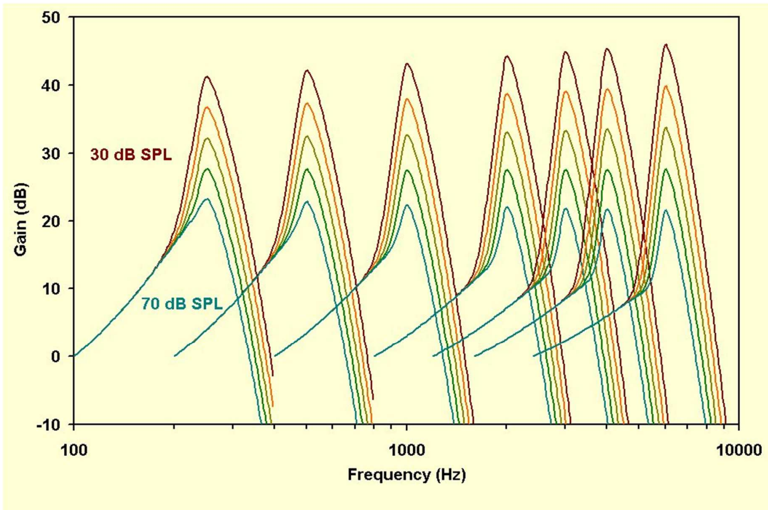
Auditory filter shapes across level & frequency: Note the asymmetry



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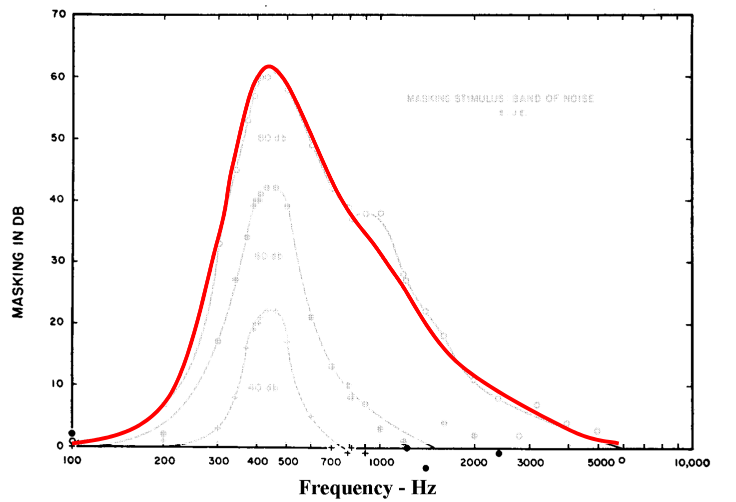
Low masks high, but not v.v. Excitation patterns



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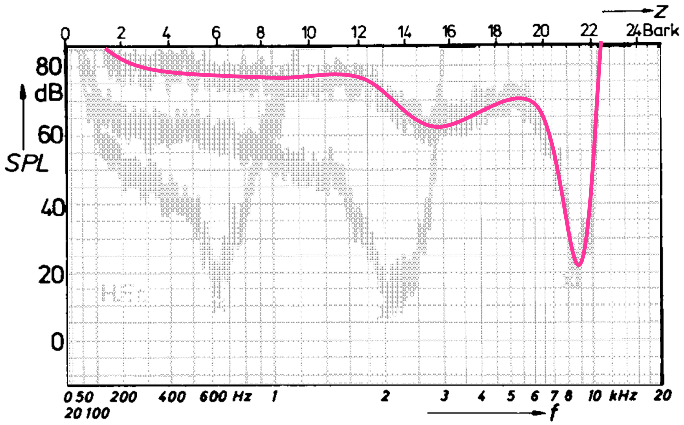
Low masks high, but not v.v. Frequency responses



Main points

- The “filters” through which we listen to sounds are the filters established in the inner ear, in SNHL as well as normal hearing.
  - supported by the similarity between physiological and behavioural measurements
- The width of the auditory filter is an important determinant in how well we can hear sounds in noise (which is almost always).
- People will use whatever information is available to them, even when the task is as trivial as detecting a tone.