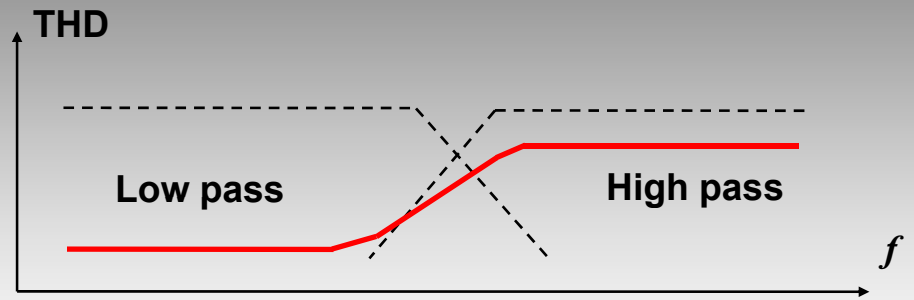
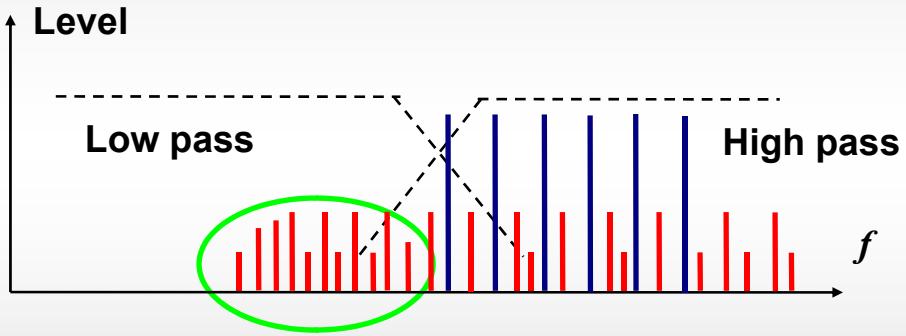
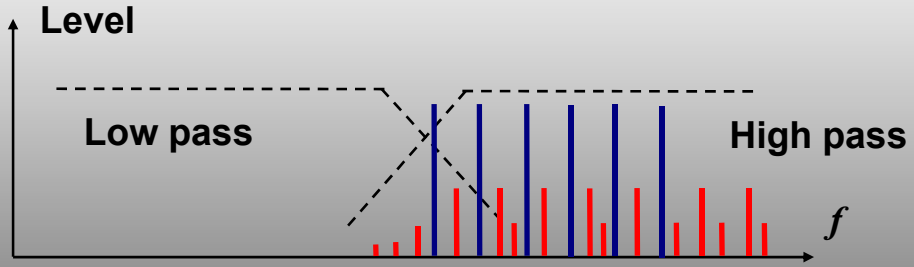
Distortion and masking



THD before and after connection of the second high-pass filter

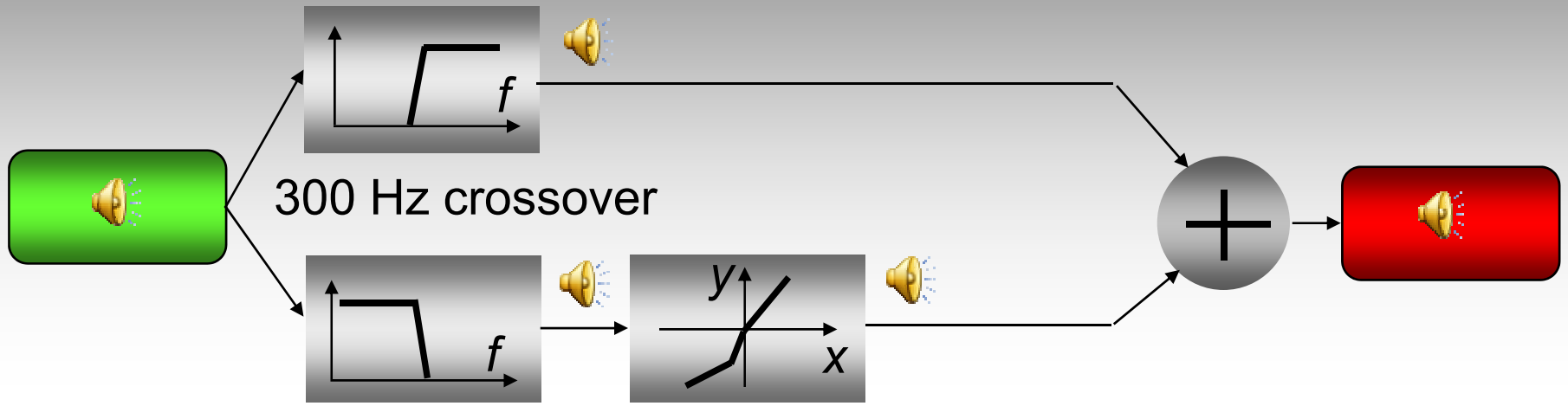


Reaction to multitone stimulus before connection of the second high-pass filter
It reveal difference-frequency IM products invisible to THD

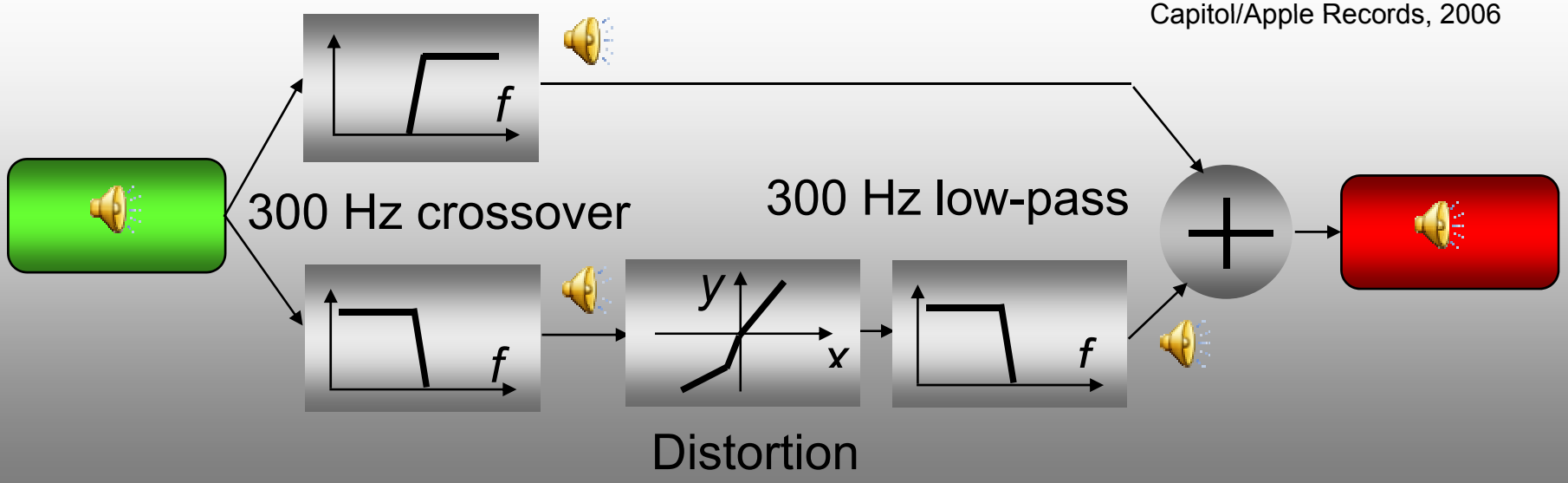


Reaction to multitone stimulus after connection of the second high-pass filter

Distortion and masking



Musical excerpt from The Beatles
"Come Together", CD "Love",
Capitol/Apple Records, 2006

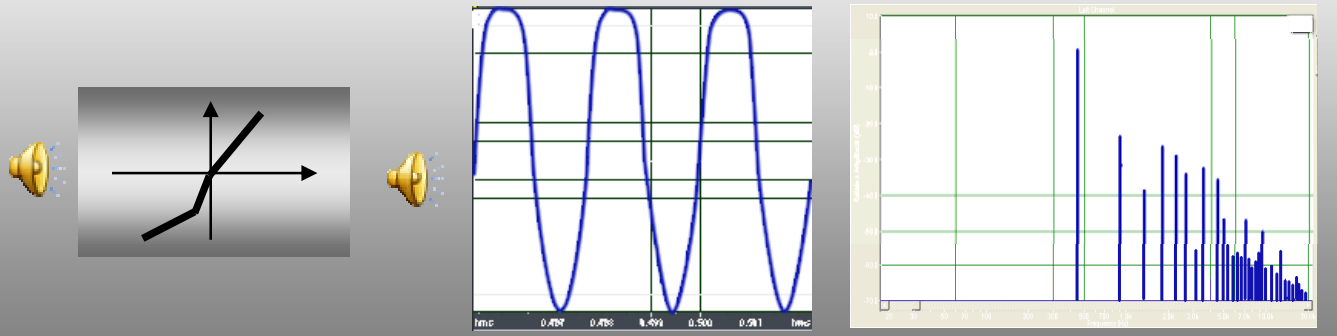


Distortion and masking

- **Nonlinear products that fall outside the spectrum of the signal are very noticeable and irritating.**

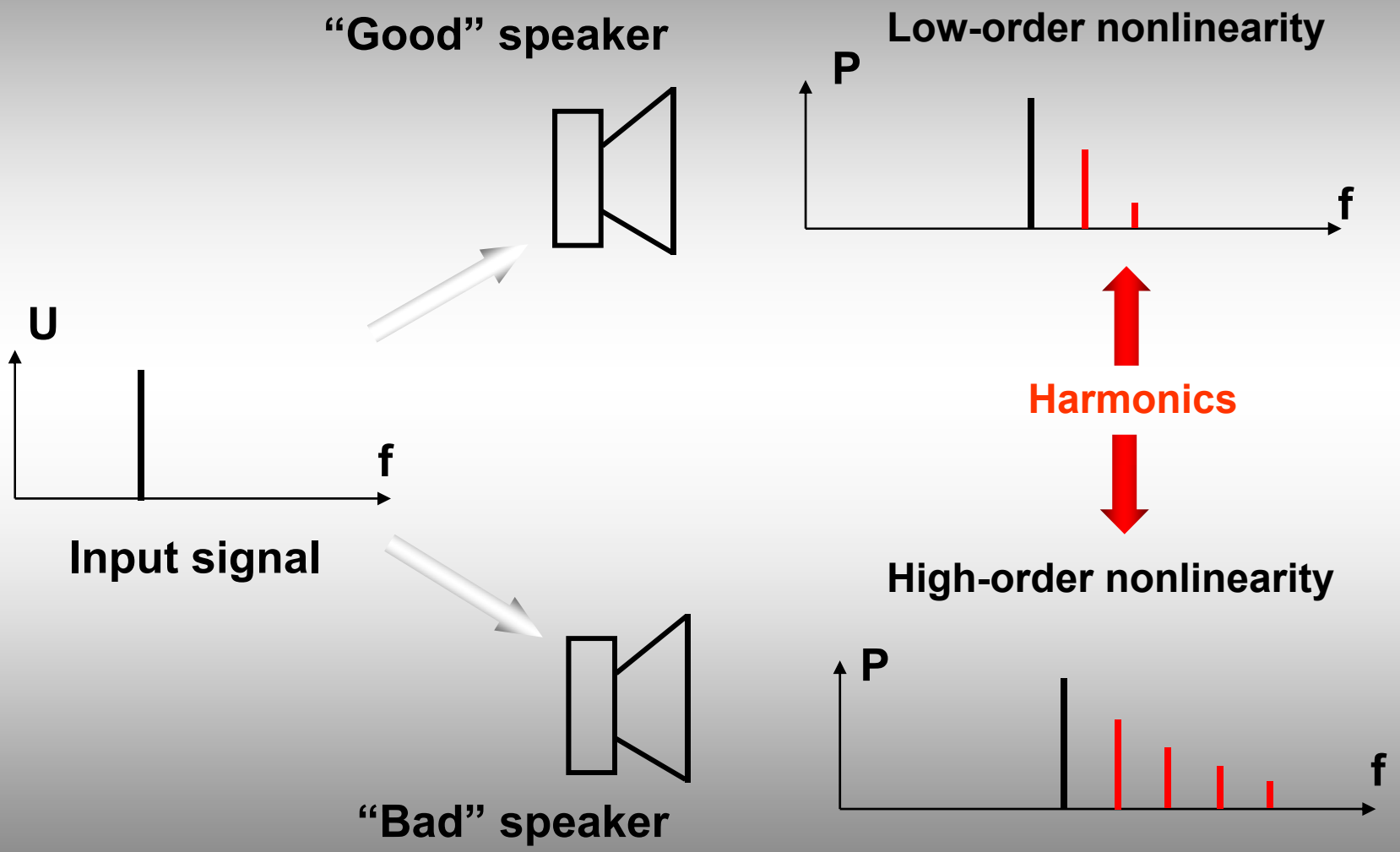
- **Masking plays significant role in mitigating irritating effect of nonlinear distortion.**

The same nonlinearity produces the following effect on 440 Hz tone:

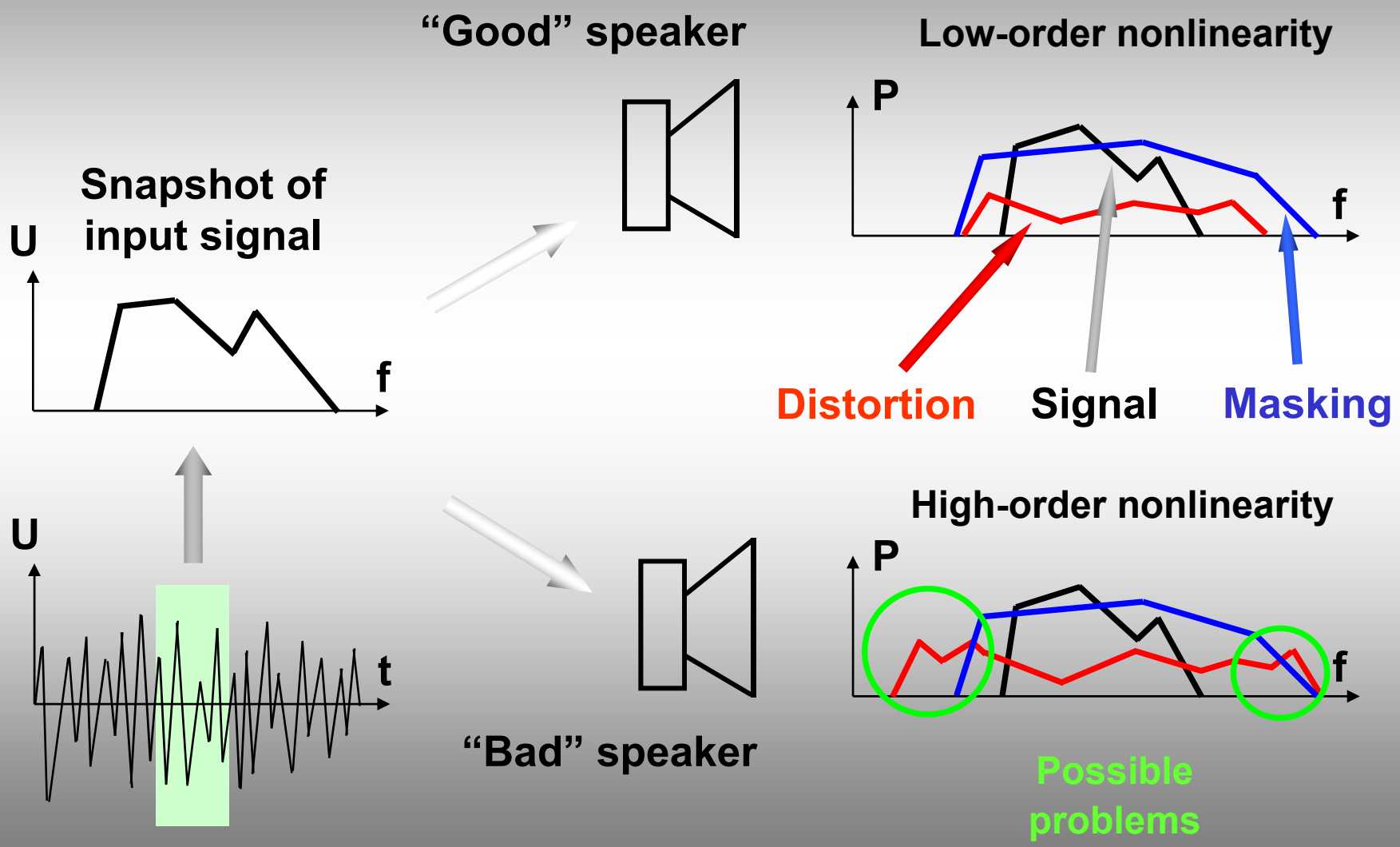


THD = 15%

Low and high-order nonlinearity

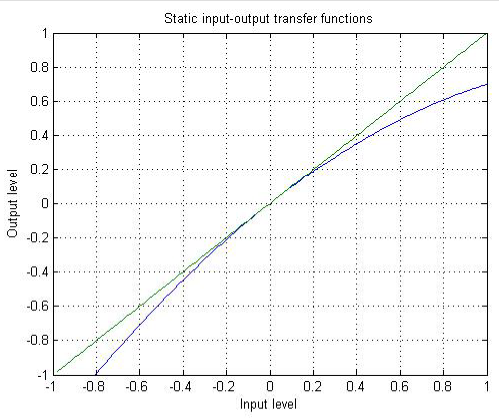


Low and high-order nonlinearity

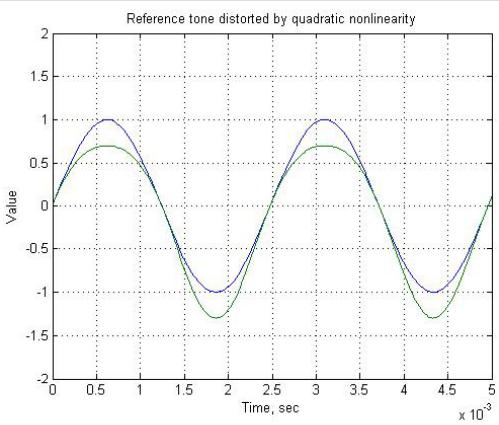


Low and high-order nonlinearity

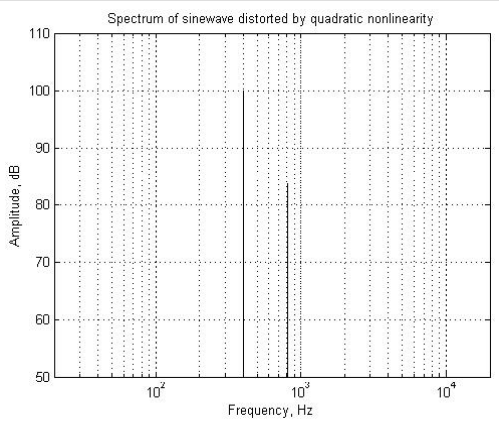
2nd order nonlinearity,
THD = 15%



Nonlinear function



Tone waveforms



Tone spectrum

Original musical signal

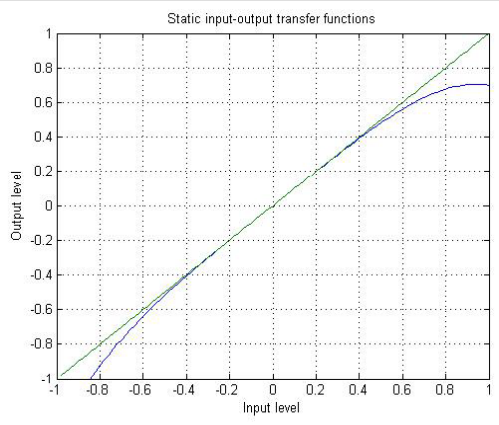
Distorted musical signal

Distortion signal only

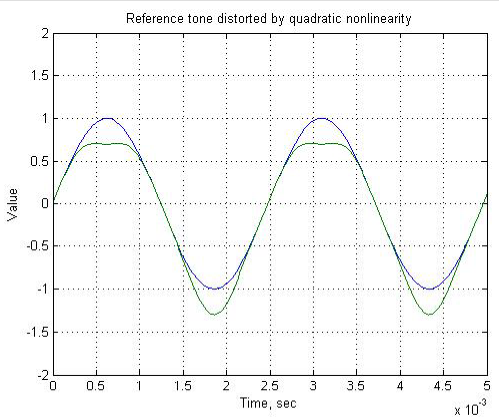
Musical excerpt from Janis Ian “His Hands”, CD “Breaking Silence”, Morgan Creek Records, 1993

Low and high-order nonlinearity

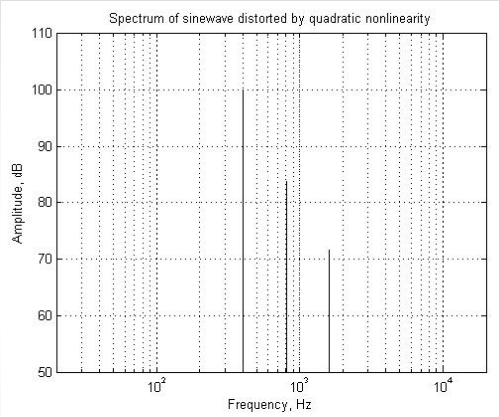
4th order nonlinearity, THD = 15%



Nonlinear function



Tone waveforms



Tone spectrum

Original musical signal

Distorted musical signal

Distortion signal only

Musical excerpt from Janis Ian “His Hands”, CD “Breaking Silence”, Morgan Creek Records, 1993

Three approaches to assessment of nonlinearity in audio

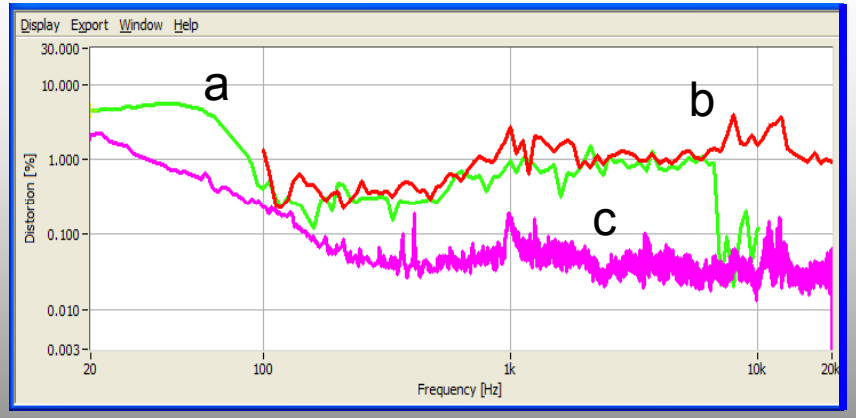
Identification	Distortion measurement	Perceptual methods
Obtaining enough information to predict reaction to an arbitrary signal	Obtaining certain symptoms of nonlinearity	Simulation of psychoacoustical effects responsible for perception of sound quality
Klippel analyzer	IMD, THD, harmonics, multitone, coherence function	PEAQ, PESQ

History - measurement

Non-coherence and broadband stimuli. S. Temme and P. Brunet, 2006.

The authors introduced a Non-Coherent Distortion (NCD) measure. The measure is based on consideration of weakly nonlinear systems and the assumption that the output signal is a superposition of the linear component, nonlinear component and noise. They demonstrated that the non-coherence $[1\text{-}\gamma^2(i\omega)]$ applied to the overall output signal's autospectrum $G_{yy}(\omega)$ is the autospectrum $G_{NN}(\omega)$ of the uncorrelated (distortion+noise) signal. Based on this, the NCD was introduced as:

$$\eta^2(\omega) = \frac{G_{NN}(\omega)}{\sum_{\omega} G_{YY}(\omega)}$$



Example of testing 6" x 9" car loudspeaker: a – Normalized THD, b – Difference Frequency IM distortion, c - NCD

Classification of “semi-perceptual” and perceptual methods

Semi-perceptual

Harmonics weighting. Gedd-Lee metric. “Pass-band” noise weighting

Better correlation with sound quality than harmonics and 2-tone IM , but limited application

Perceptual methods

Codecs measurement

Transducers measurement

Psychoacoustics-based

Hearing system physiology-based

Significantly better correlation with perceived quality

Semi-perceptual methods

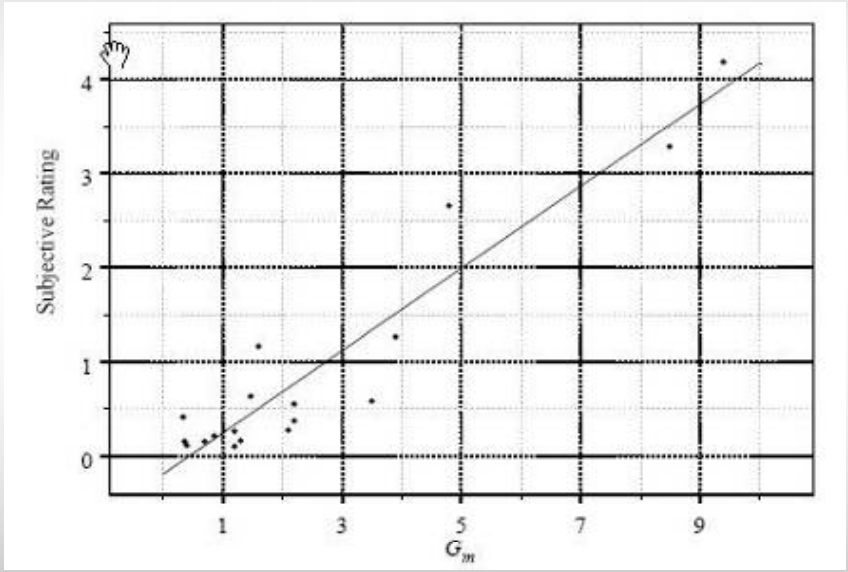
Gedd-Lee metric. E. Geddes, L. Lee, 2003

This metric stays between objective and perceptual methods because the metric does not use explicitly models of auditory system, but is based on the following psychoacoustical assumptions:

- High-order nonlinearity $T(x)$ produces wide spectrum of distortion products that are poorly masked
- Nonlinearity that affects signal at low levels (e.g. zero crossing) is worse than nonlinearity that affects only high level signal (e.g. hard clipping) because low-level signals are poor maskers

$$G_m = \sqrt{\int_{-1}^{1} \left(\cos\left(\frac{x\pi}{2} \right) \right)^2 \left(\frac{d^2}{dx^2} T(x) \right)^2 dx}$$

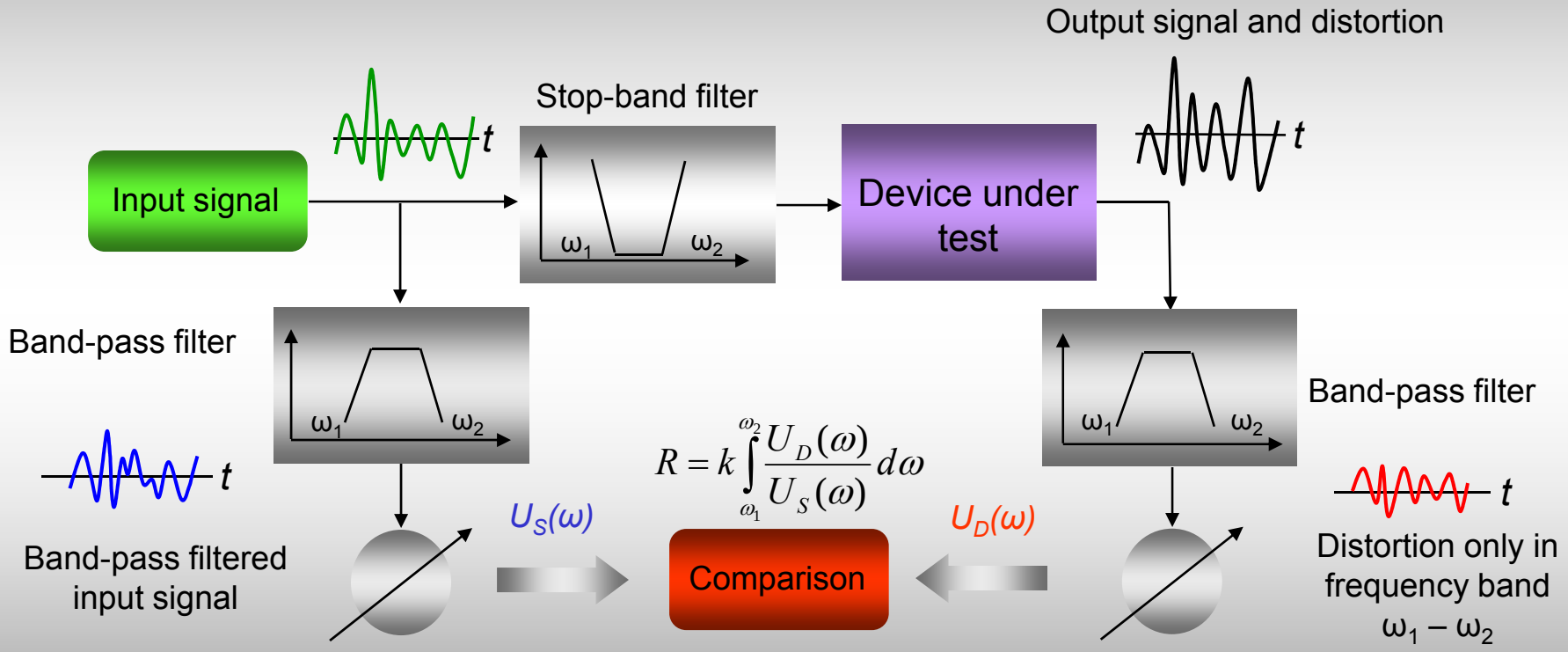
$T(x)$ – static nonlinearity



Subjective rating versus Gm

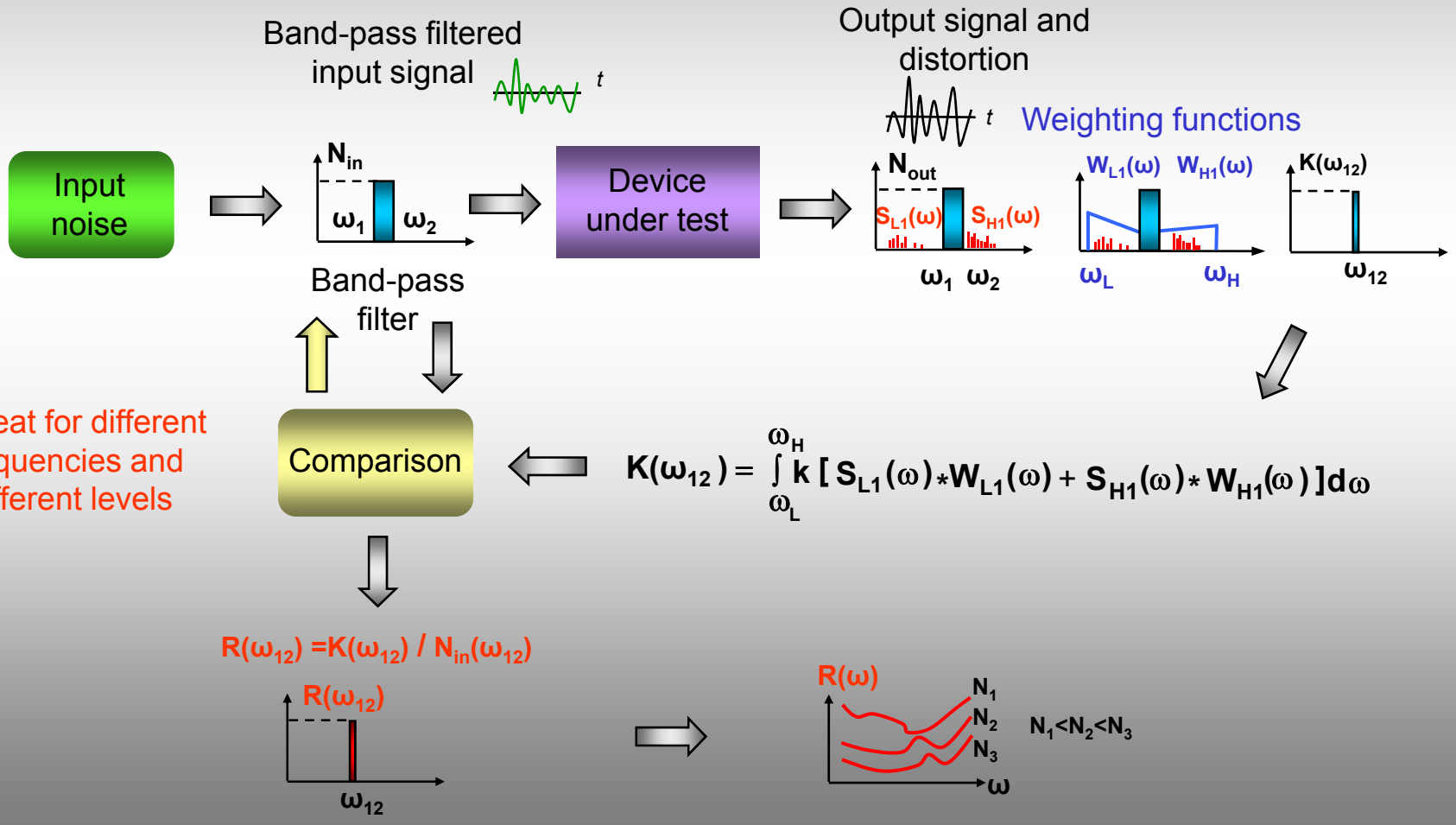
Semi-perceptual methods

Measurement of distortion using musical signal, V. Wolf, 1953

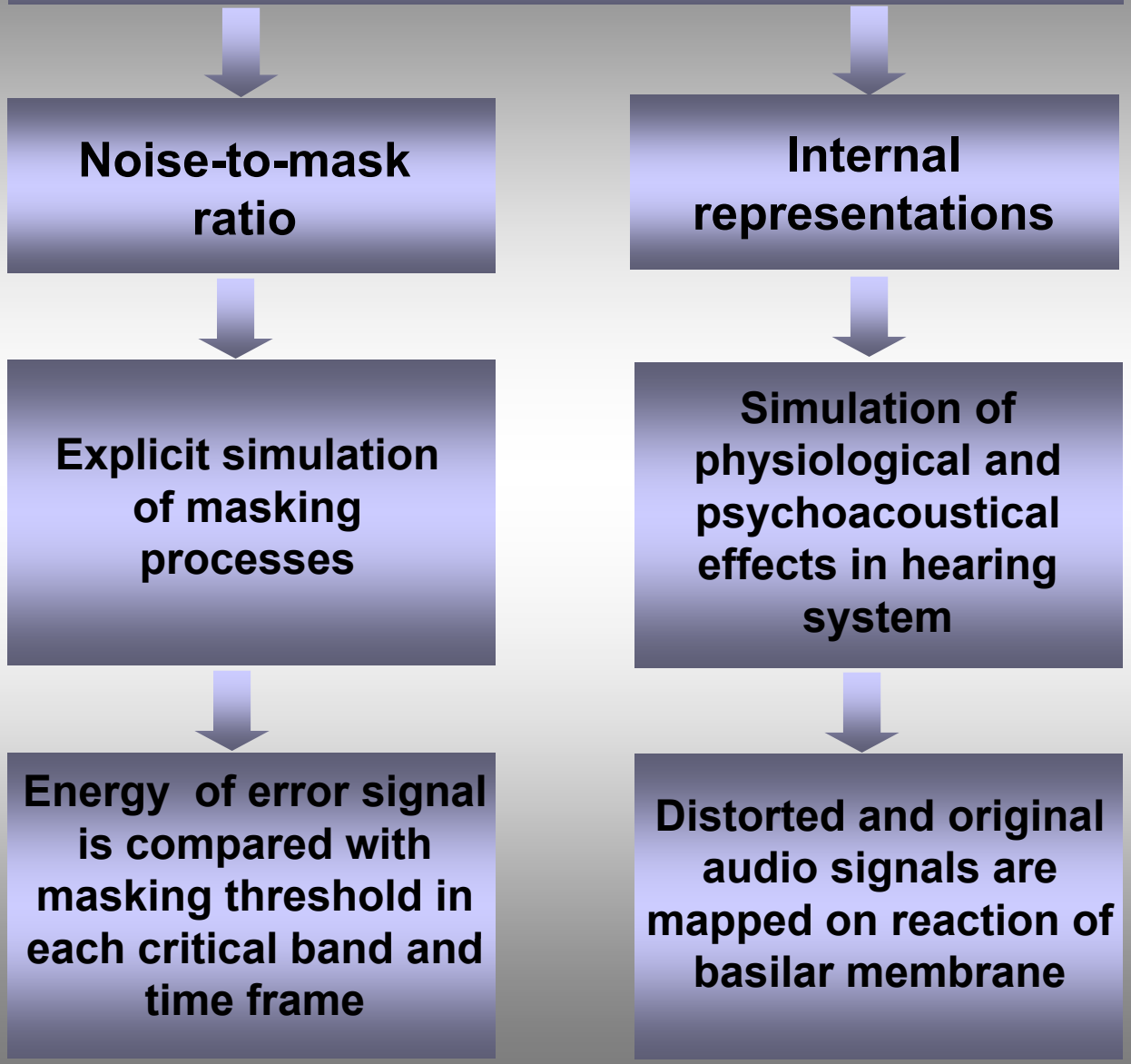


Semi-perceptual methods

Alternative semi- perceptual methods using weighting functions, Voishvillo, 2007

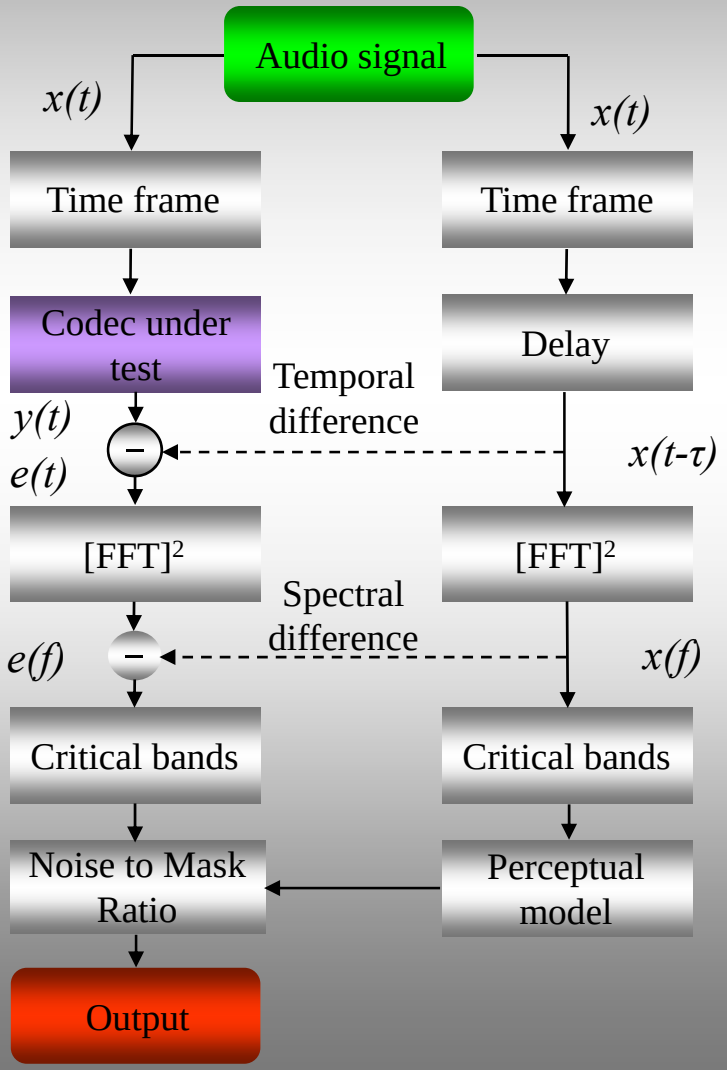


Perceptual methods



Perceptual methods

Perceptual models based on noise-to-mask ratio



Explicit simulation of masking process

R. Beaton et. al. "Objective Measurement of Audio Quality", *Collected Papers on Audio Bit-Rate Reduction,* AES, 1996