# "Transmitter"

## Sources of nonlinearity in a horn driver

**Electrodynamic nonlinear effects**
* Nonlinear Bl-product
* Bl-product modulation by voice coil current
* Voice coil inductance variation with displacement
* Quadratic reluctance force
* Inductance dependence on current. Magnetic hysteresis
* Eddy currents. Modulation of resistive losses

**Mechanical nonlinear effects**
* Nonlinear mechanical suspension. Diaphragm and surround breakups
* Non-harmonic effects.

**Acoustical nonlinear effects**
* Nonlinear sound propagation in phasing plug and horn
* Nonlinearity and modulation of compression chamber air compliance
* Nonlinearity and modulation of compression chamber air mass
* Nonlinearity and modulation of air viscosity in compression chamber
* Nonlinear relationship between particle velocity and sound pressure
* Nonlinear air compression in rear chamber
* Air turbulence in phasing plug ?
* Air turbulence in voice coil gap?
* Air turbulence in compression chamber?

# “Transmitter”

Loudspeaker is a nonlinear dynamic system

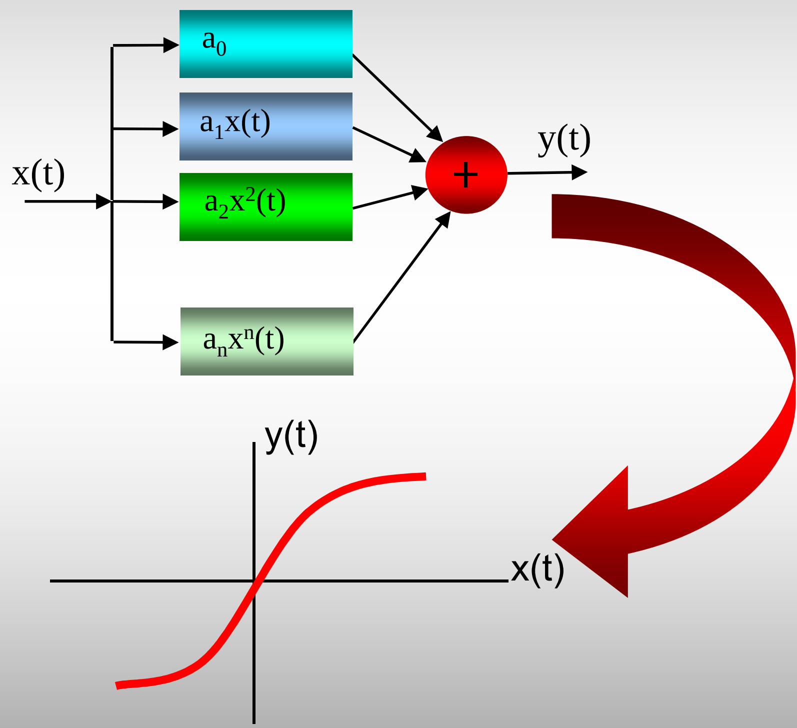
There is a significant  difference between:

Dynamic nonlinear system and static nonlinear system

Dynamic nonlinear system and dynamic linear system

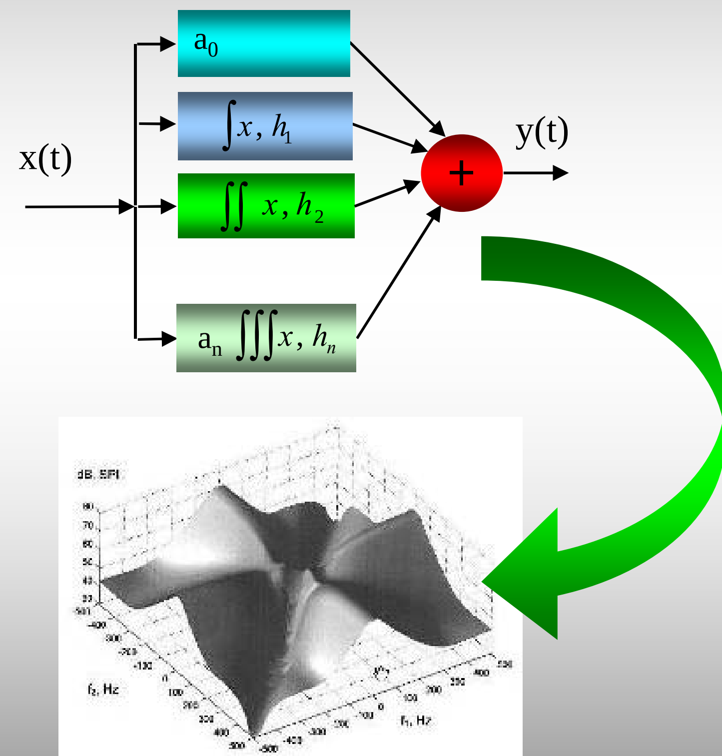
# Static versus dynamic nonlinearity

## Static nonlinearity (simple)




Linear and nonlinear responses do not depend on frequency

## Dynamic nonlinearity (complex)




Second-order nonlinear response of a loudspeaker.

# Linear dynamic system measurement

Input signal: Sweeping tone, impulse or noise → Dynamic linear system under test → Output reaction: Impulse response or complex transfer function

↓

Output reaction to any signal can be predicted → Full description!

# Nonlinear dynamic system measurement

**Input signal: Sweeping tone, two tones**

→

**Dynamic nonlinear system under test**

→

**Output reaction: harmonics, THD, two-tone IM products**

↓

**Output reaction to any signal cannot be predicted**

←

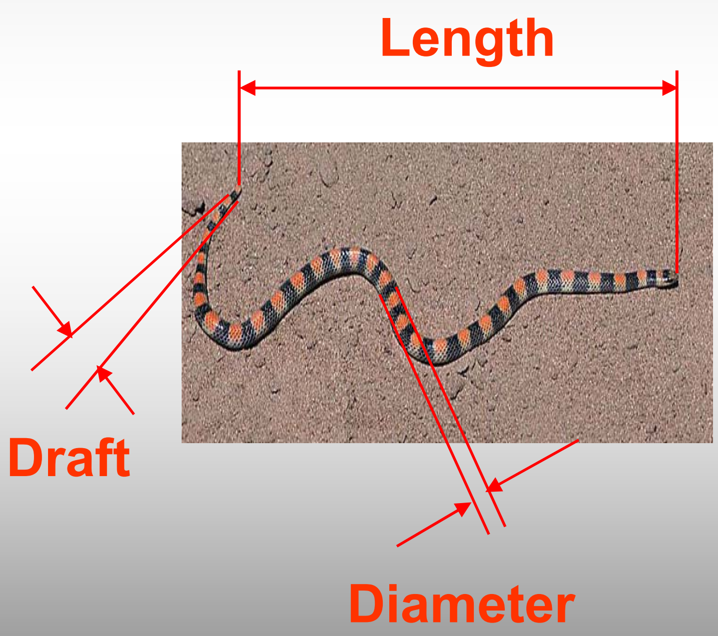
**Harmonics and IM products are only symptoms of nonlinearity**

ALMA
"The International Loudspeaker Association"

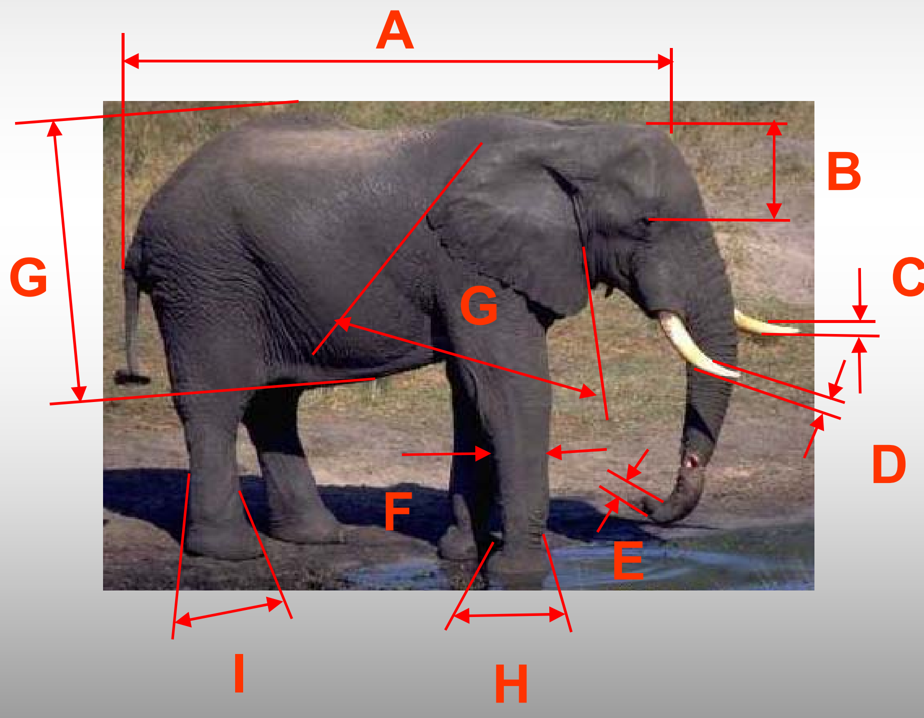
# Linear dynamic versus nonlinear dynamic system

JBL PROFESSIONAL

## Linear dynamic system (simple)

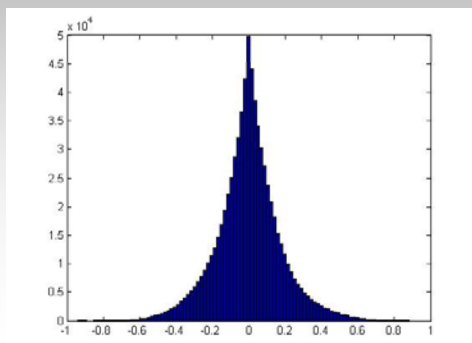



## Nonlinear dynamic system (complex)



# “Signal”

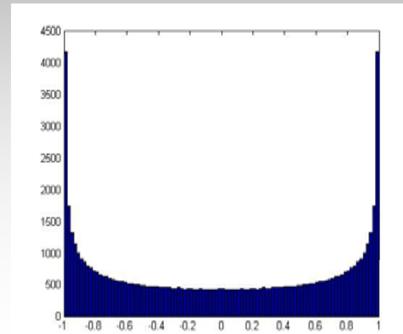
Musical signal




**Amplitude**

Statistical distribution

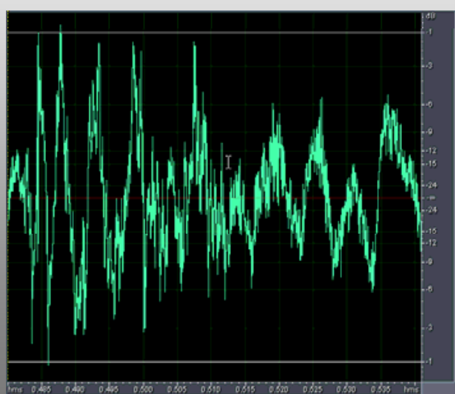
Sinusoidal signal



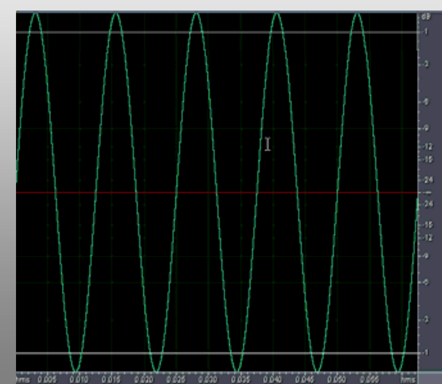

**Amplitude**

**Musical signal remains at low levels most of the time and the peaks are rare**

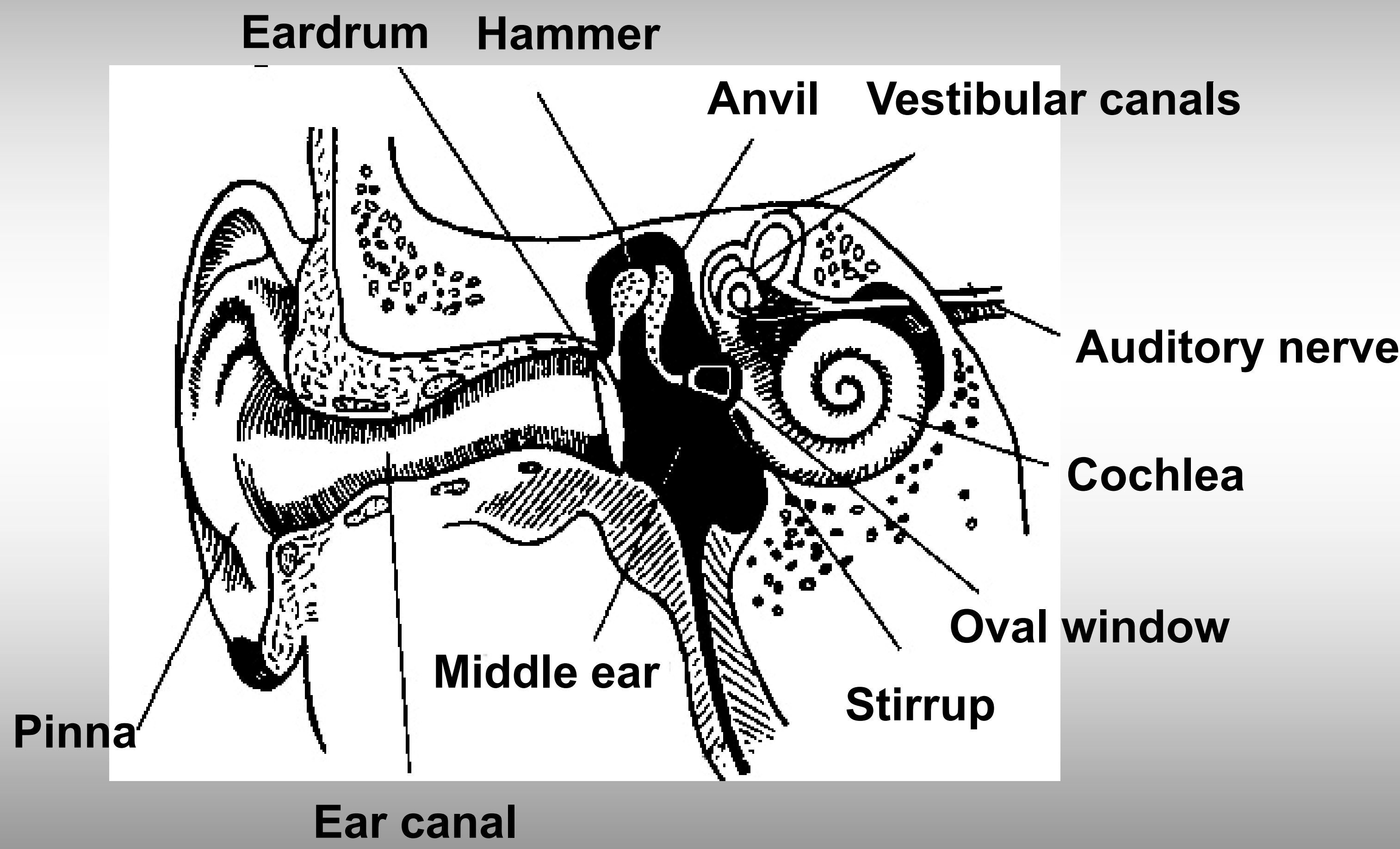
**Sinusoidal signal is opposite. It remains at large levels most of the time**



Waveform

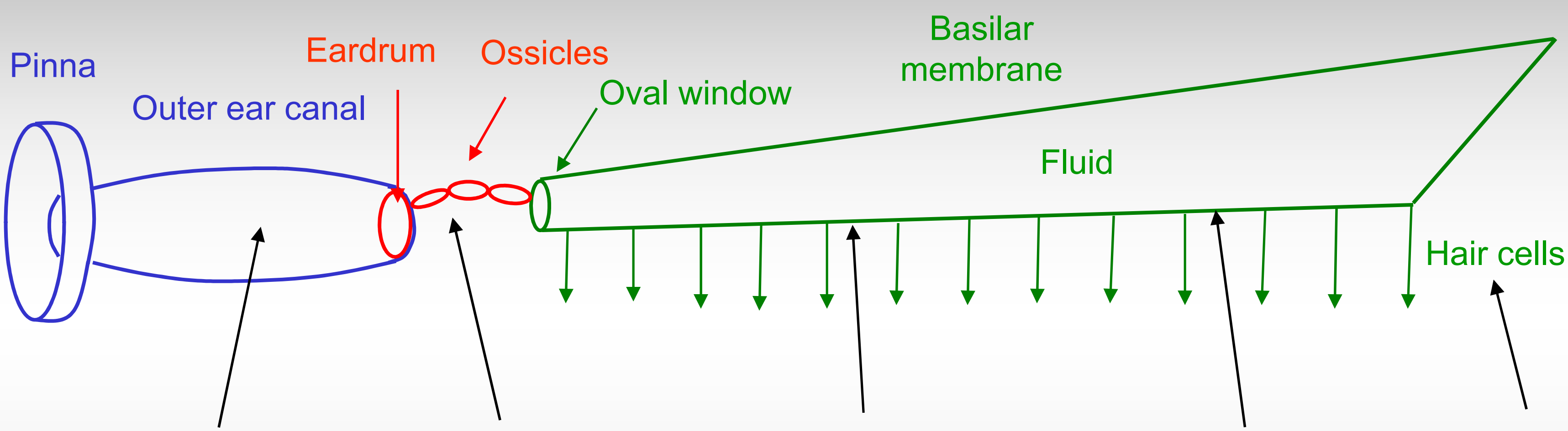


# “Receiver” - hearing system, psychoacoustics

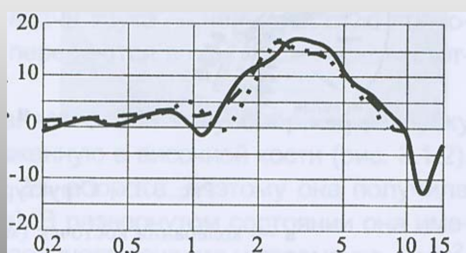


# “Receiver” - hearing system, psychoacoustics

OUTER EAR MIDDLE EAR INNER EAR




Resonances in the ear canal

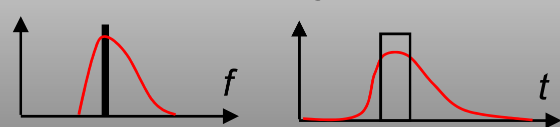



Reflex – protects inner ear from “overload” by the middle ear muscles contraction

Spreading – excitation of areas on basilar membrane in the vicinity of the location responsible for a particular signal

Compression – “amplification” of low-level sounds

Transformation of mechanical vibrations into electrical impulses



# “Receiver” - hearing system, psychoacoustics

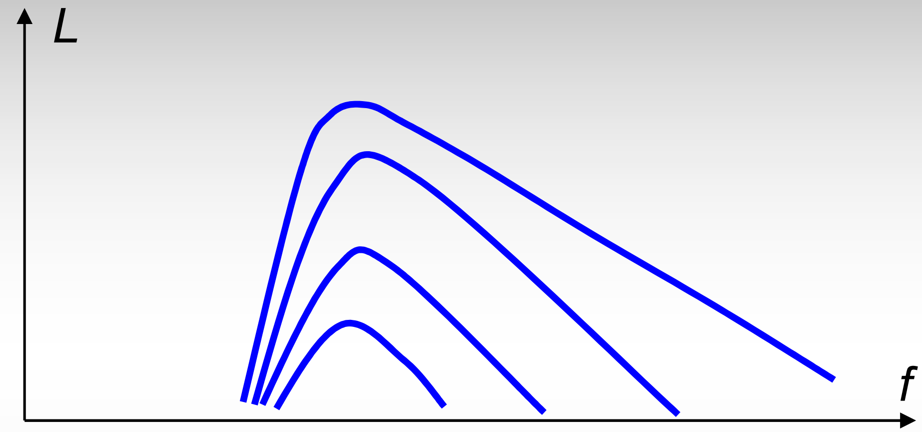
- **Spreading**
- **Masking**
- **Critical bands**
- **Loudness**
- **Compression**

# "Receiver" - hearing system, nonlinearity

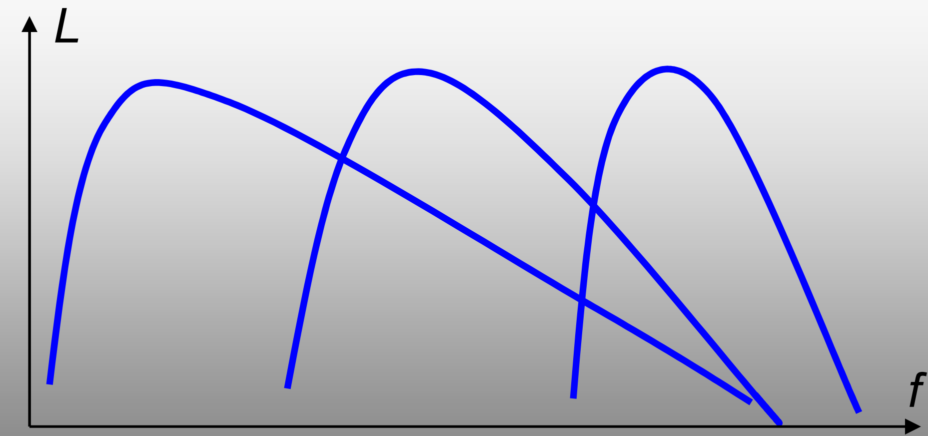
- **Middle ear nonlinearity and acoustic reflex**
- **Inner ear – nonlinear compression**
- **Cochlea nonlinear otoacoustic emission**
- **Cochlea – turbulence of the fluid**
- **Basilar membrane – nonlinear mechanics**
- **Hair cells – nonlinear excitation**
- **Nonlinear auditory filtering**

# Simultaneous masking

## Masking versus level and frequency

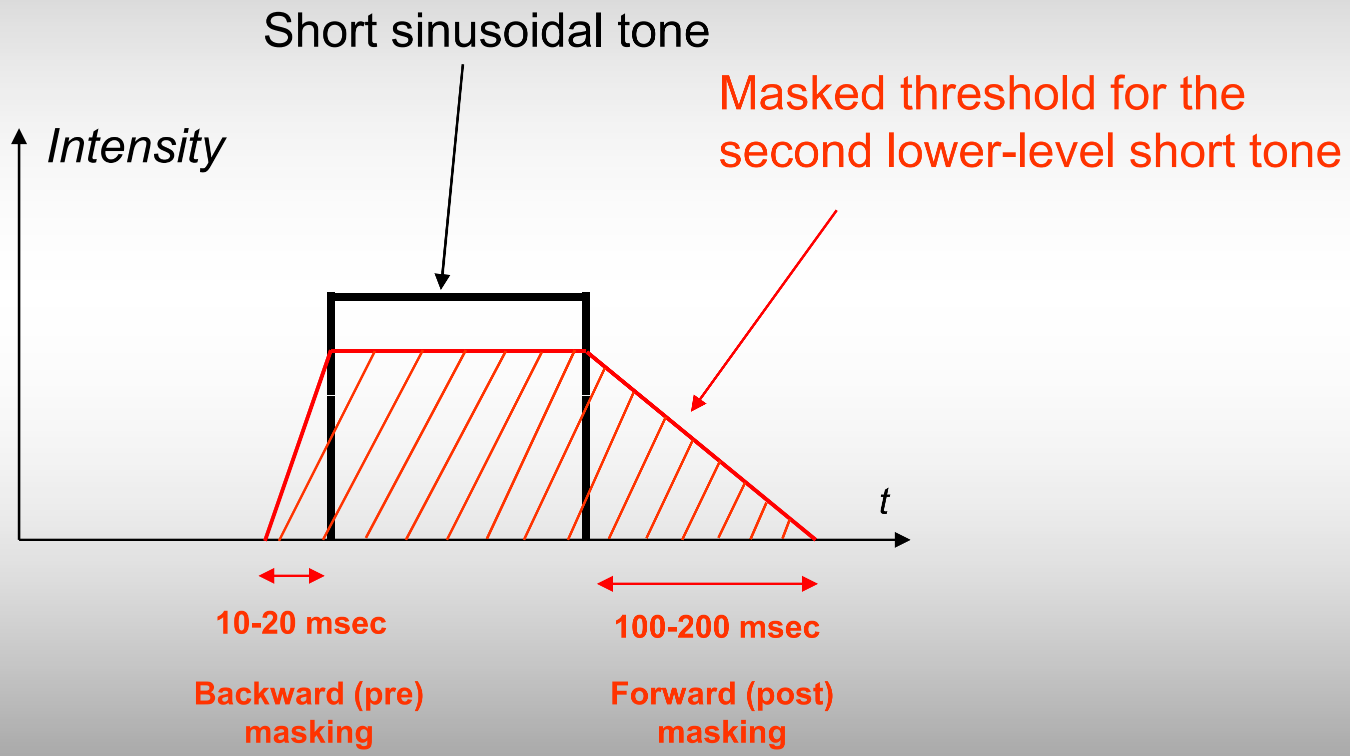



Masking curve becomes progressively asymmetric at higher levels of masker




Lower-frequency masking extends over wider frequency range.

# Time-domain masking

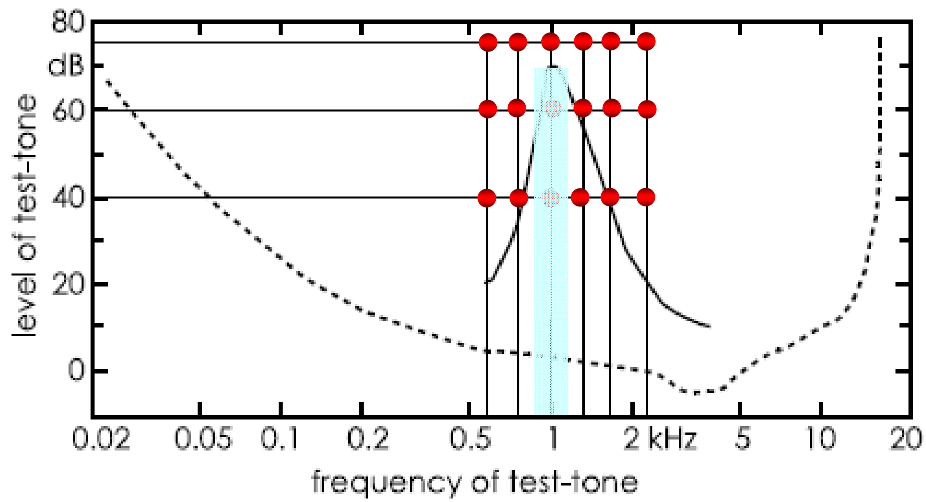


# Simultaneous masking

**Track 10: Pure tones masked by narrow-band noise**

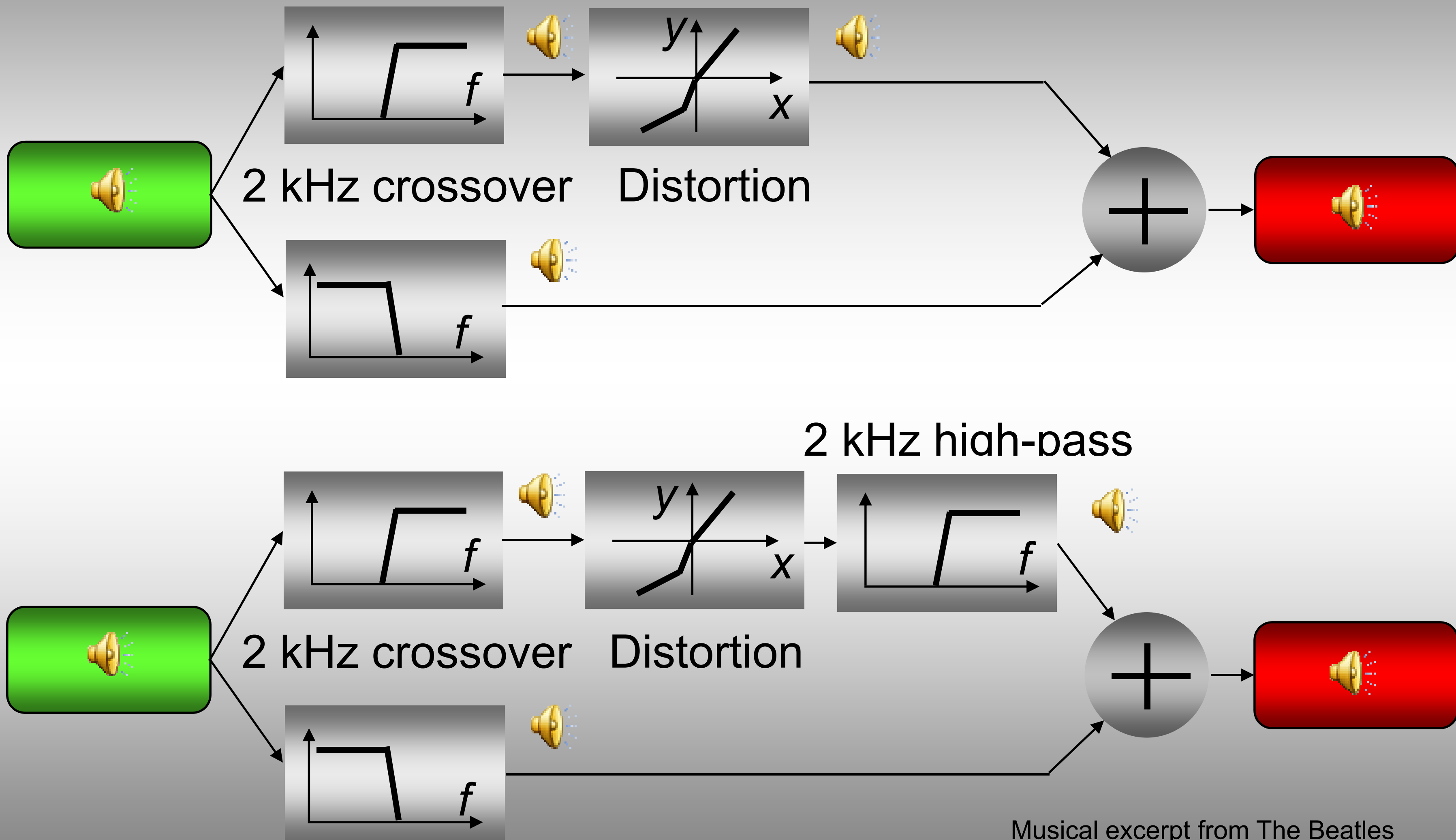
0:56

In this demonstration the masked threshold of pure tones masked by critical-band wide noise (1 kHz, 70 dB) is illustrated. You will hear three series of tone triplets: the first series is played at a level of 75 dB, the second at a level of 60 dB, the third at a level of 40 dB. Each series consists of six tone triplets with the frequencies 600 Hz, 800 Hz, 1000 Hz, 1300 Hz, 1700 Hz, and 2300 Hz. In the second series the third tone triplet at 1000 Hz is masked by the narrow-band noise, and in the third series the third and fourth triplet at 1000 Hz and 1300 Hz (for some persons also the fifth triplet at 1700 Hz) are masked. (cf. Fig. 4.4)




Fastl and Zwicker, “Psychoacoustics. Facts and Models”, Springer 2006

# Distortion and masking




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