



Reflection gives Satisfaction

Basics of geometrical and statistical acoustics

1 Geometrical Acoustics

- 1.1 Reflections on Straight Surfaces
- 1.2 Reflection and Wavelength
- 1.3 Room Modes (Standing Waves)
- 1.4 Reflections on curved Surfaces
- 1.5 Interfering vs. Useful Reflections

3 Live Measurement of the Lecture Room

- 3.1 Measurement with Akucheck
- 3.2 Measurement with Audition and Aurora

2 Statistical Acoustics

- 2.1 Audibility and Reverberation
- 2.2 The Sabine Formula
- 2.3 Reverberation Radius
- 2.4 Further Characteristics of Audibility:
 - 2.4.1 Speech and Music Clarity Indices
 - 2.4.2 Bass Ratio and Strength
 - 2.4.6 Lateral Fraction



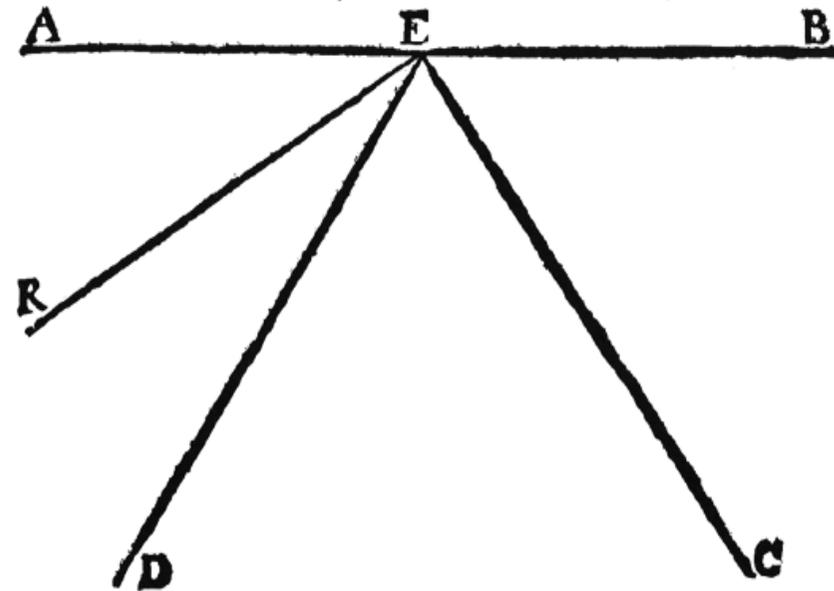
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1 Geometrical Acoustics

Sound wave and sound ray

The path of a **sound wave** can also be considered as a straight line or **sound ray**.

Erster Lehr-Satz. Propositio I.
Ein jeglicher Thon-werffender Winkel ist gleich dem zurücks
werffenden / oder welches eben so viel ist / wie der Thon-Winkel
ist von der Stelle da er aufgehet / so ist auch der / so
zurück-pröllet.



Angle of Incidence = Angle of Reflection
(Kircher 1684, p. 12-13)



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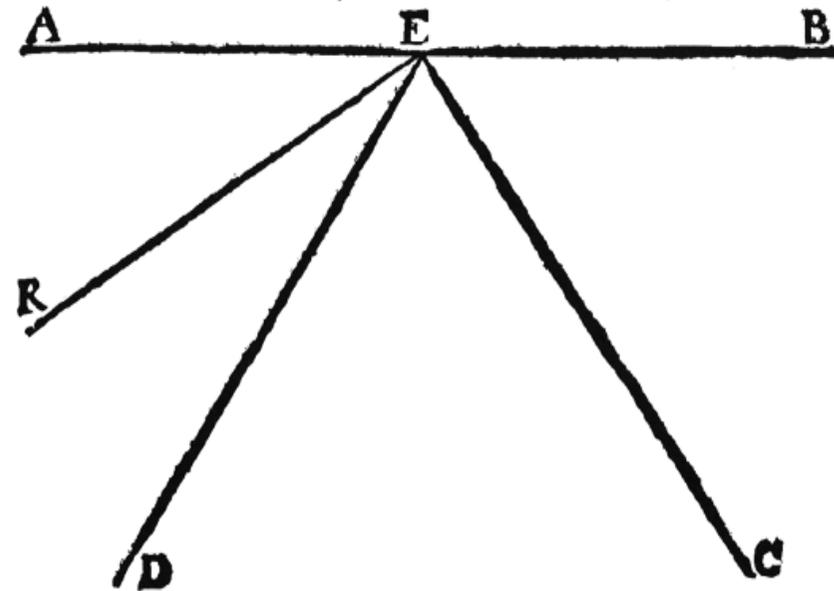
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1 Geometrical Acoustics

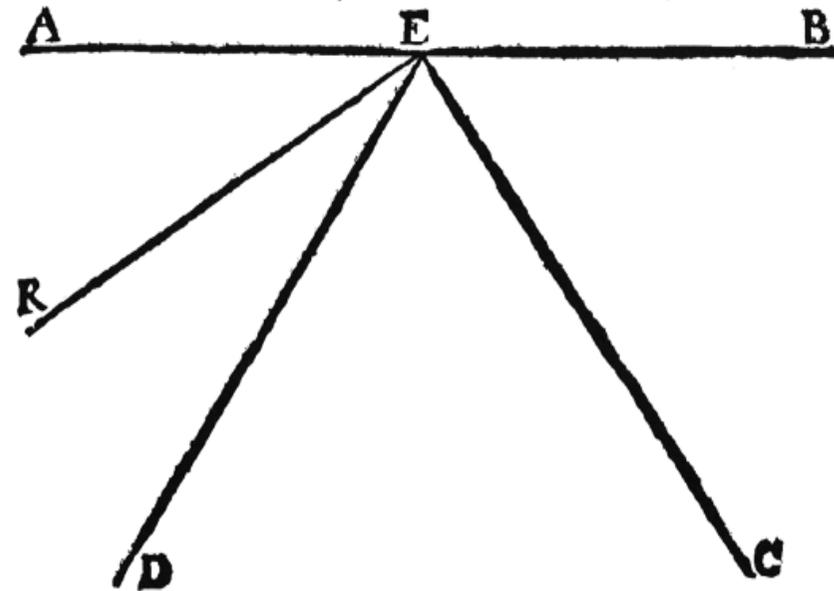
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So it is possible to describe the path of sound rays with the **laws of optics**.

The most basic law is here:
angle of incidence = angle of reflection

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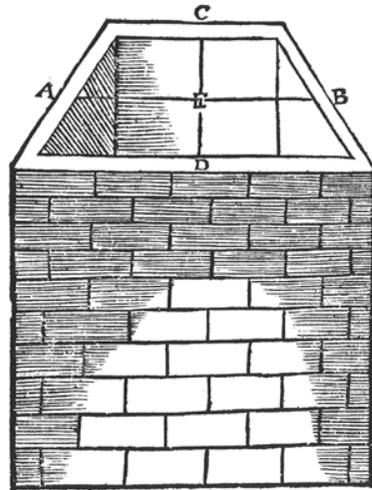
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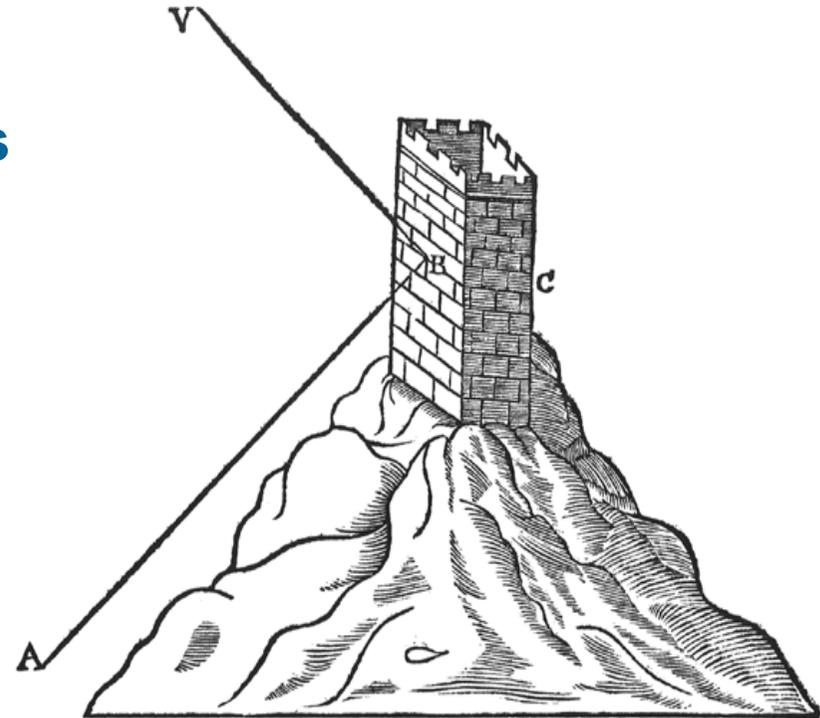
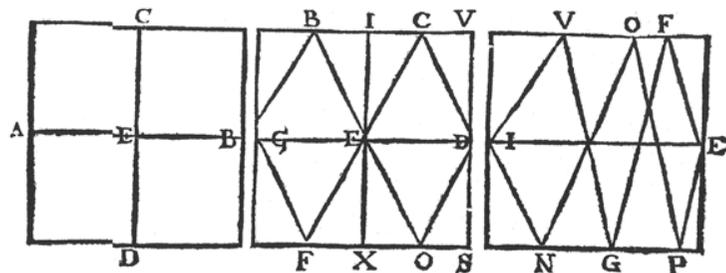
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1.1 Reflections on Straight Surfaces

Dreyzehender Lehr-Satz. Propositio XIII.
 Wann das Stimm-centrum oder Mittel-punct in die Mitterlinie
 hohen Vier-Ecks gestellet wird/so wird die außgelassne Stimm oder
 Tyon vierfach vermehret zu ihrem centro oder Mittel-
 puncten widerkommen.



Reflections on
 sound rays starting
 from the center of
 a square-shaped
 room
 (Kircher 1684,
 p. 24-25)



Weiter/ wann die Stimm oder Tyon auß A. kommt/ und der widerhallende Gegenz-
 Stand oder Wand seye B.C. ein Thurn eines Berges; So sag ich/ daß die Stimm auß
 A in B. und von dannen in V schalle. Die Ursach ist eben wie in vorgehenden; dann weil
 die Stimm oder Tyon schräg oder schlems in B fällt/ so muß nohtwendig die Stimm
 gleich-winkelicht in V. widerhallen/ und das wurde eben auch geschehen/ wann die Stimm
 auß V. käme/ so wurde der Wider-Hall in A. geschehen/ wie die Figur außweiset/ auß
 welchem besagt/ und erwisenem wir folgende regula machen.

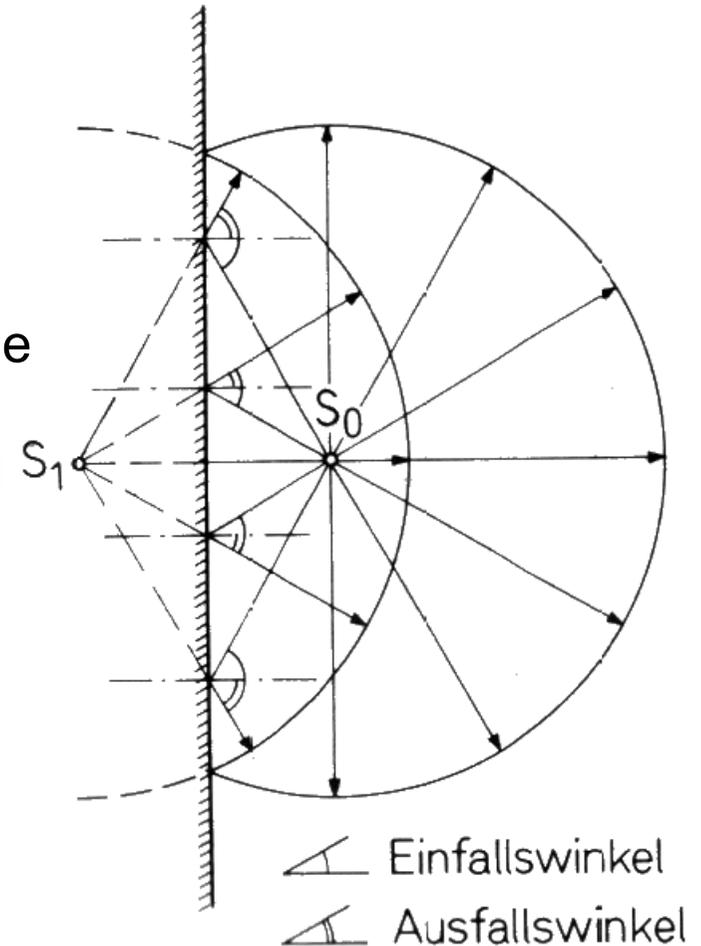
Angle of Incidence = Angle of Reflection
 (Kircher 1684, p. 15)



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1.1 Reflections on Straight Surfaces

In the case of a reflection on straight surfaces, one speaks theoretically about a **mirrored sound source** behind the surface from which the **sound rays** can be calculated.



Reflection on a straight surface

(S_0 : original sound source,

S_1 : mirrored sound source)

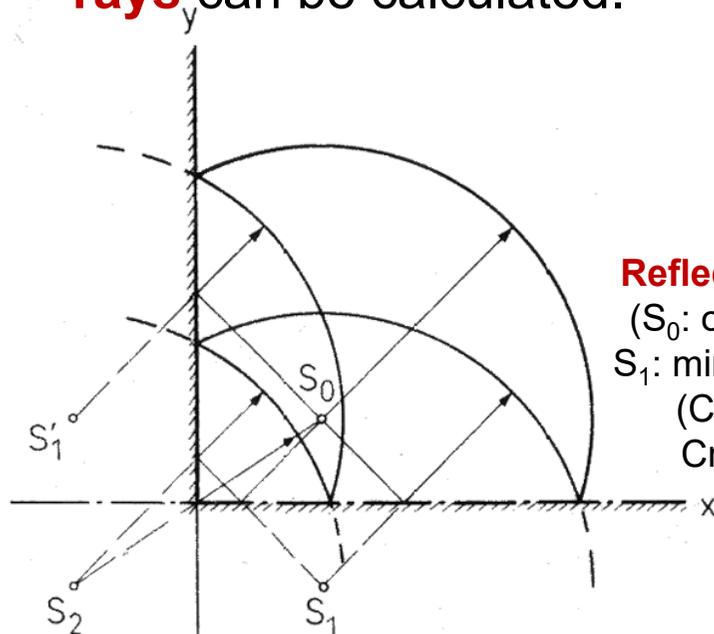
(Cremer 1948, p. 17; Cremer 1978, p. 21)



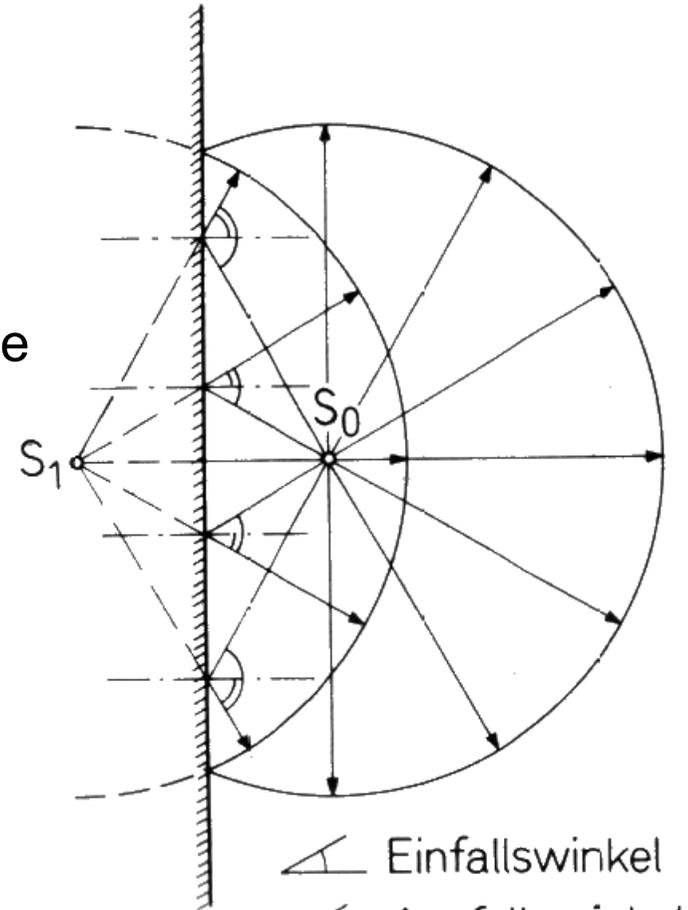
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1.1 Reflections on Straight Surfaces

In the case of a reflection on straight surfaces, one speaks theoretically about a **mirrored sound source** behind the surface from which the **sound rays** can be calculated.



Reflection in a right angle
 (S_0 : original sound source,
 S_1 : mirrored sound source)
 (Cremer 1948, p. 19;
 Cremer 1978, p. 24)



Reflection on a straight surface
 (S_0 : original sound source,
 S_1 : mirrored sound source)
 (Cremer 1948, p. 17; Cremer 1978, p. 21)

 Einfallswinkel
 Ausfallswinkel



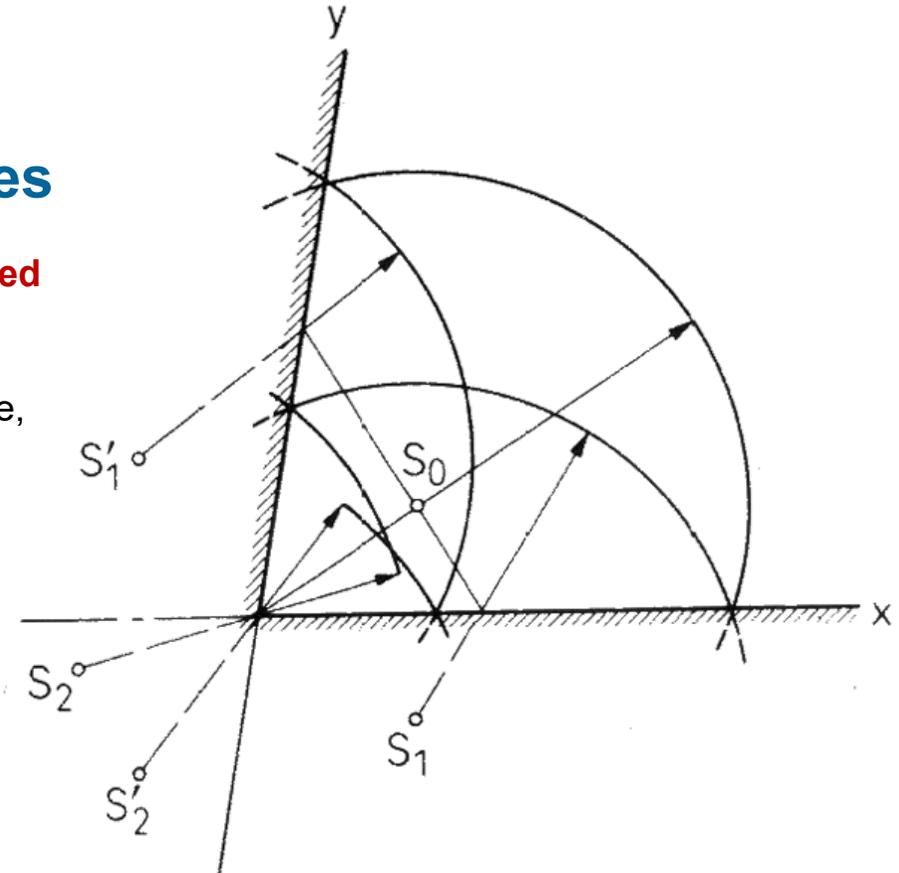
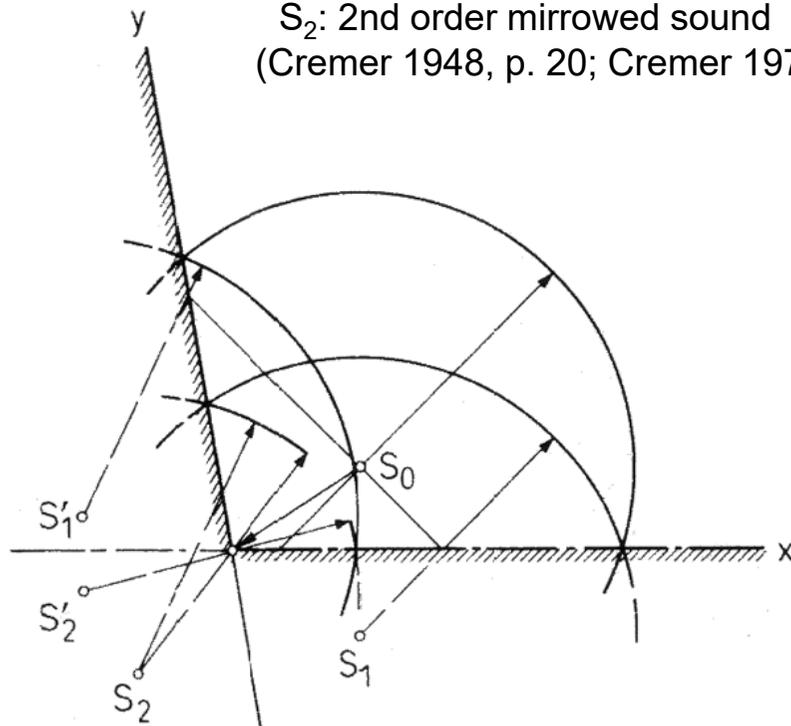
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1.1 Reflections on Straight Surfaces

Reflection at an obtuse angle -> sound gets scattered

There are two sources of sound in each case, rays are deflected outwards along the wall angle.

(S_0 : original sound source, S_1 : mirrored sound source, S_2 : 2nd order mirrored sound source)
(Cremer 1948, p. 20; Cremer 1978, p. 24)



Reflection at an acute angle -> Sound is concentrated

There are two reflected sound sources each, rays are deflected inward along the wall angle

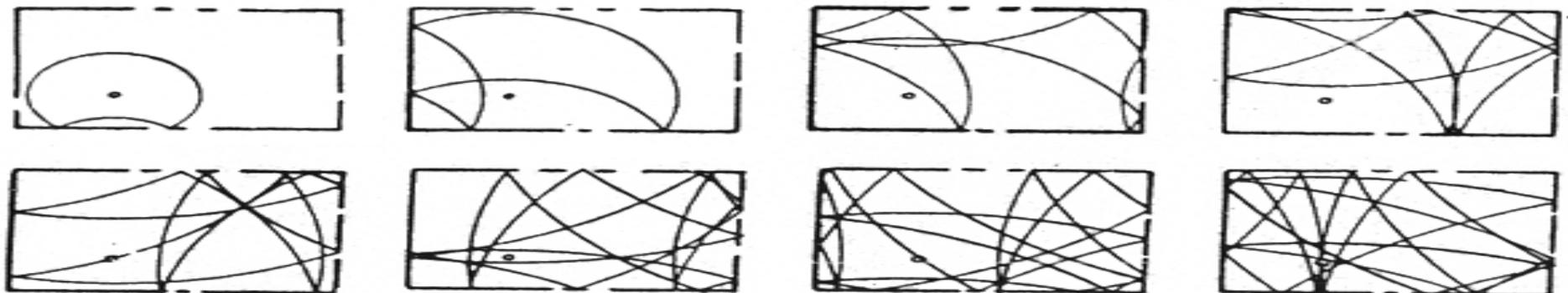
(S_0 : original sound source, S_1 : mirrored sound source, S_2 : 2nd order mirrored sound source)
(Cremer 1978, p. 24)



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1.1 Reflections on Straight Surfaces

All rooms limited by large straight surfaces lead to an **equal distribution of sound rays** after a few reflections (i.e. **diffuse** = statistically distributed sound field).



Sound propagation and reflexions inside a rectangular room (Cremer 1948, p. 22; Cremer 1978, p. 25)

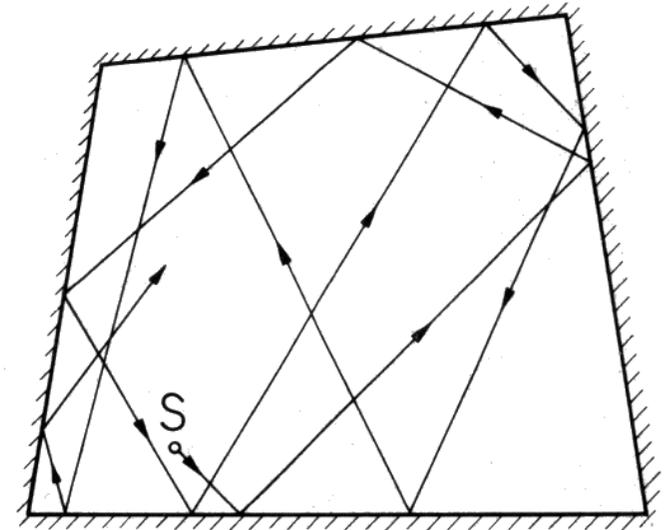


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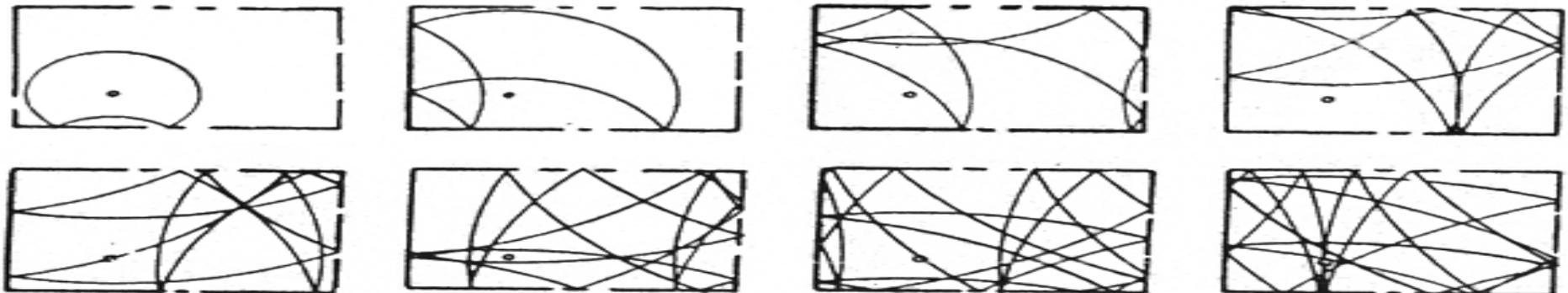
1.1 Reflections on Straight Surfaces

All rooms limited by large straight surfaces lead to an **equal distribution of sound rays** after a few reflections (i.e. **diffuse** = statistically distributed sound field).

They also lead to an **omnidirectional sound distribution**, if opposed parallel walls with similar surfaces are avoided (-> reverberation).



Reflections inside an oblique-angled room (Cremer 1948, p. 26; Cremer 1978, p. 29)



Sound propagation and reflexions inside a rectangular room (Cremer 1948, p. 22; Cremer 1978, p. 25)

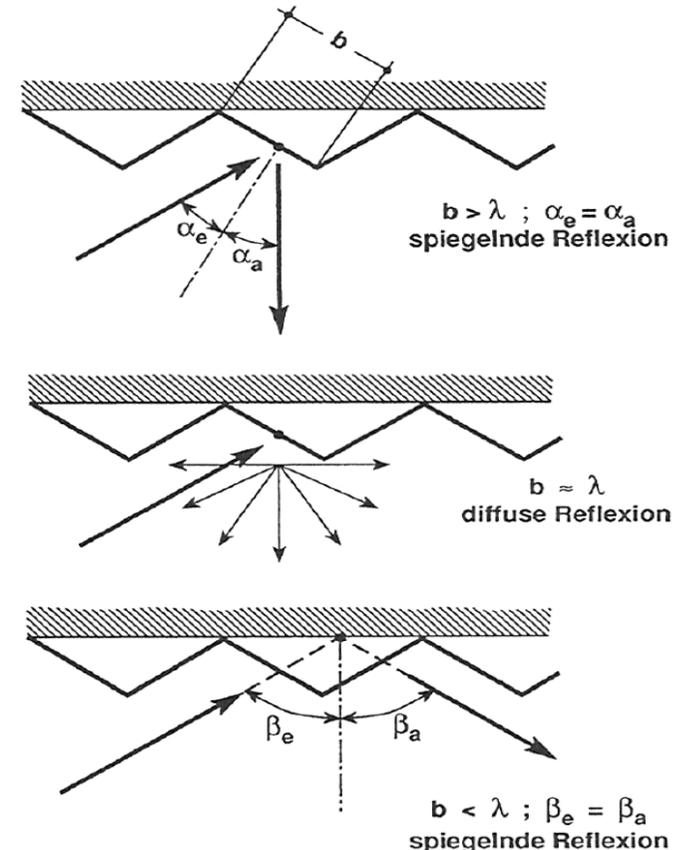


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1.2 Reflection and Wavelength

The type of reflection depends on the relationship between **wavelength** and **reflecting surface**:

1.) Wavelength is **smaller** than the reflecting surface: **mirrored reflection**
(angle of incidence = angle of reflection)



Reflexions on a surface with structures having the width b , dependent on the wavelength (Fasold, Veres 2003, p. 104)



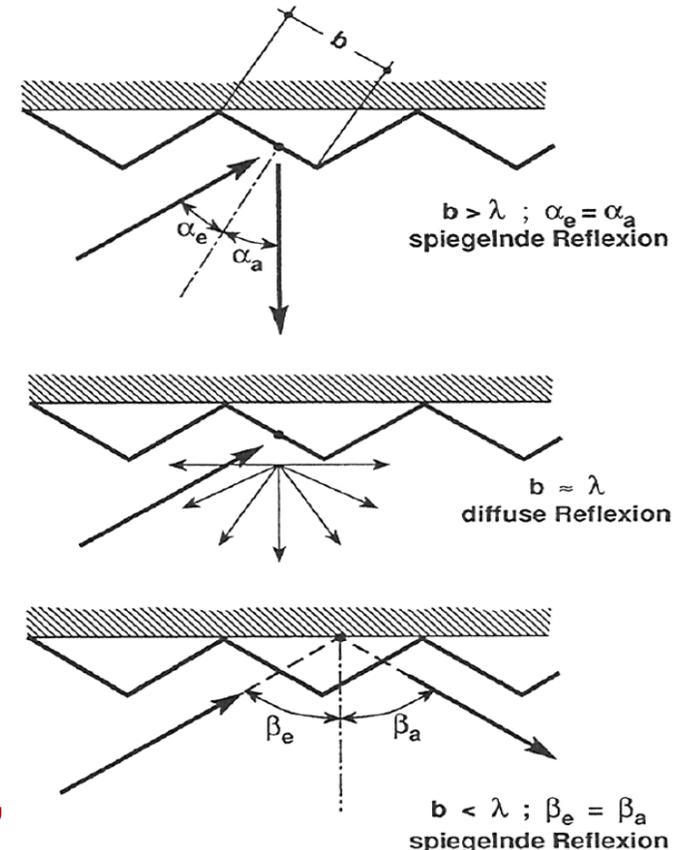
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1.) Wavelength is **smaller** than the reflecting surface: **mirrored reflection**
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2.) Wavelength **corresponds** approximately to the size of the reflecting surface: **non-directional, diffuse reflection**



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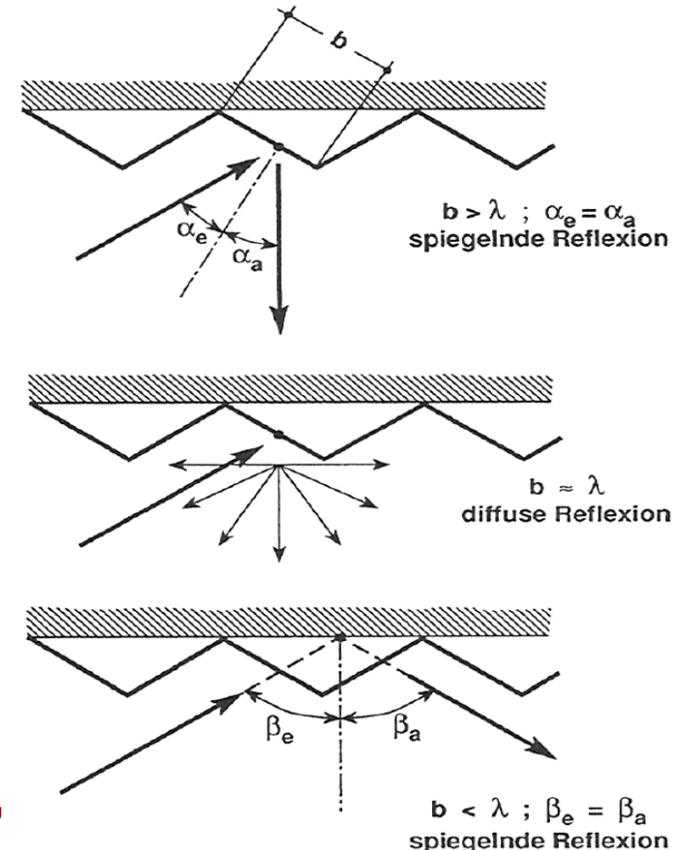
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1.) Wavelength is **smaller** than the reflecting surface: **mirrored reflection**
(angle of incidence = angle of reflection)

2.) Wavelength **corresponds** approximately to the size of the reflecting surface: **non-directional, diffuse reflection**

3.) Wavelength is **larger** than the reflecting surface: **no reflection**, or only at a larger surface behind it (if there is one)



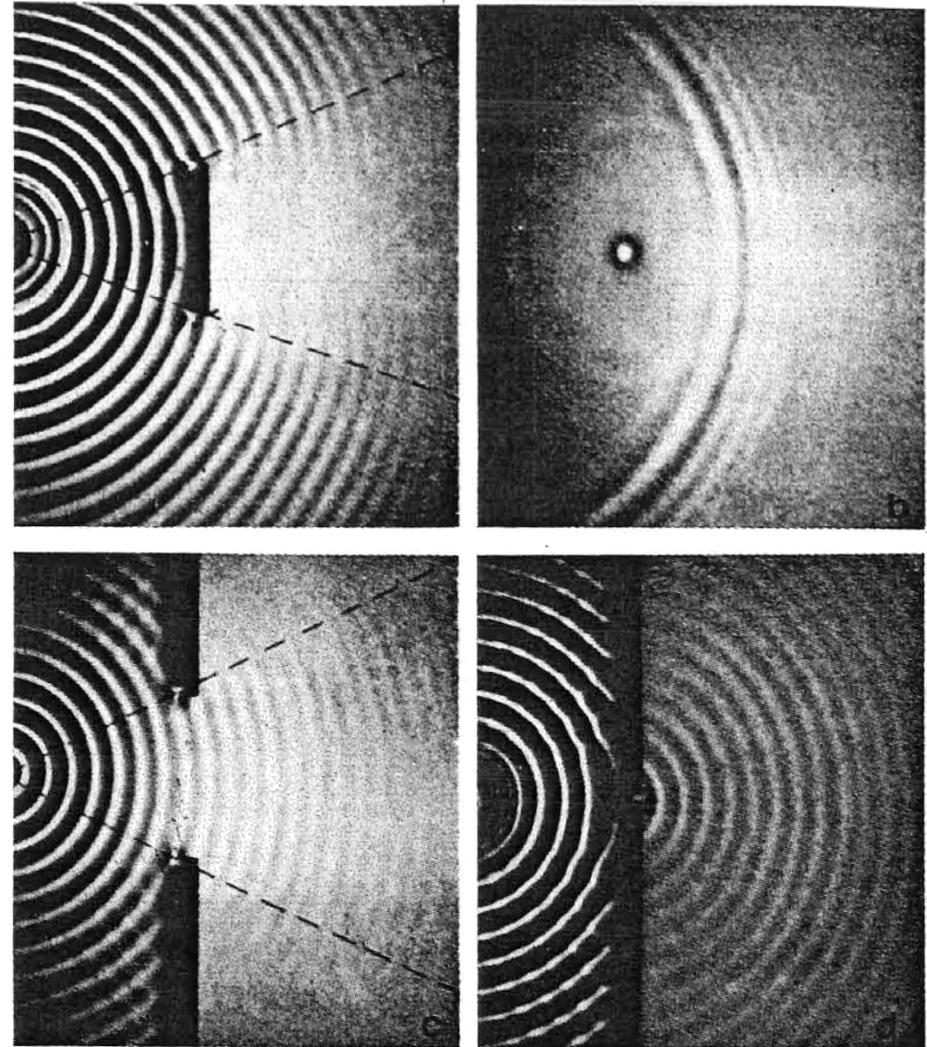
Reflexions on a surface with structures having the width b , dependent on the wavelength (Fasold, Veres 2003, p. 104)



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1.2 Reflection and Wavelength

Diffraction: Whether a sound wave is **reflected** or **diffracted** at an obstacle is determined primarily by the **size** of the obstacle compared to the **wavelength** of the sound wave.



Reflection and diffraction on a wall and on a gap
(Cremer 1978, p. 10)



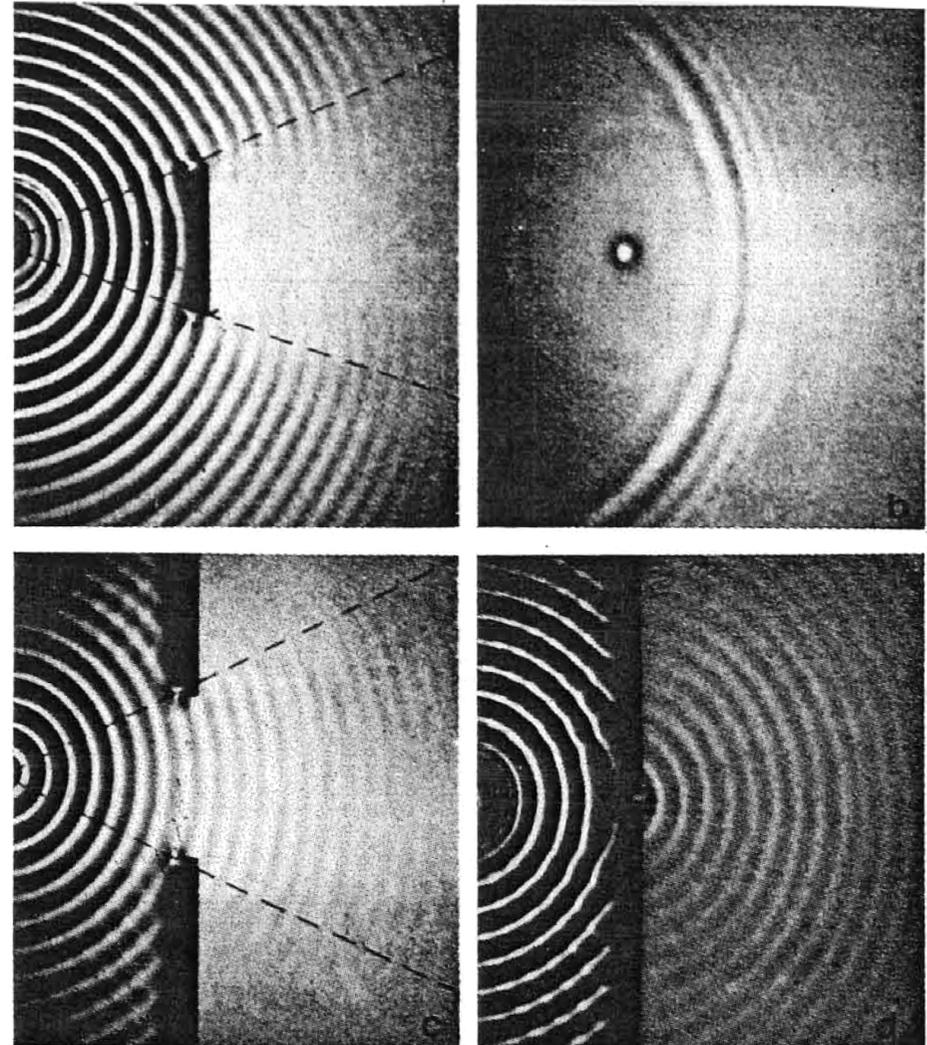
Reflection gives Satisfaction

1.2 Reflection and Wavelength

Diffraction: Whether a sound wave is **reflected** or **diffracted** at an obstacle is determined primarily by the **size** of the obstacle compared to the **wavelength** of the sound wave.

Time	Wavelength	Frequency
1 s	340 m	1 Hz
0,1 s (100 ms)	34 m	10 Hz
0,01 s (10 ms)	3,4 m	100 Hz
0,001 s (1 ms)	34 cm	1000 Hz
0,0001 s (0,1 ms)	3,4 cm	10000 Hz

Standard values for wavelengths at $c=340$ m/s
(c = speed of sound)



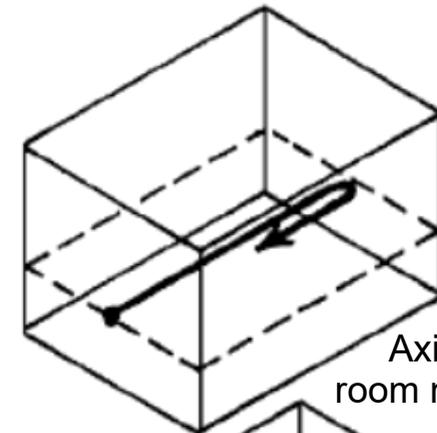
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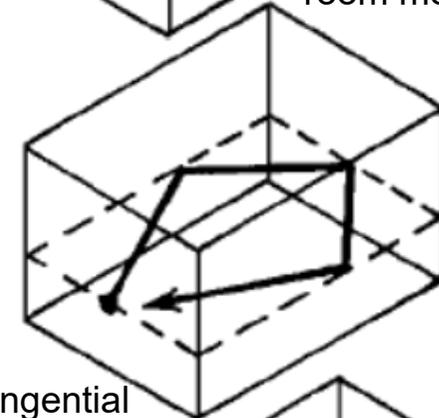
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1.3 Room Modes (Standing Waves)

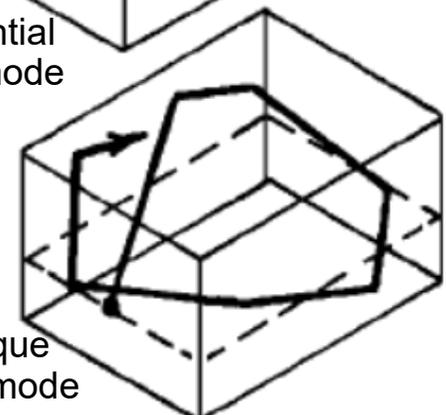
In the rise of a diffuse sound field in rooms, **standing waves** may occur at **wavelengths corresponding to a distance of two walls** (or their multiples):



Axial
room mode



Tangential
room mode



Oblique
room mode

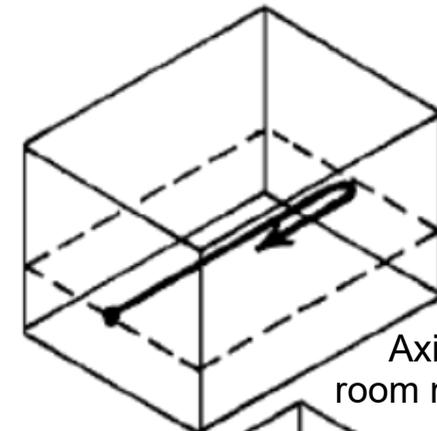


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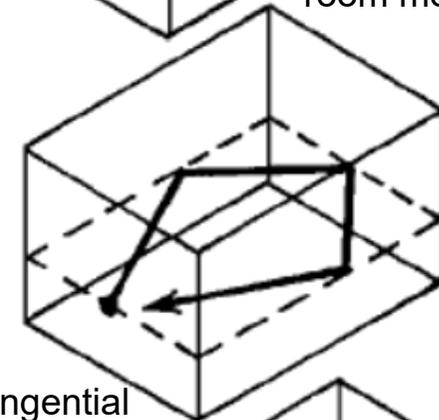
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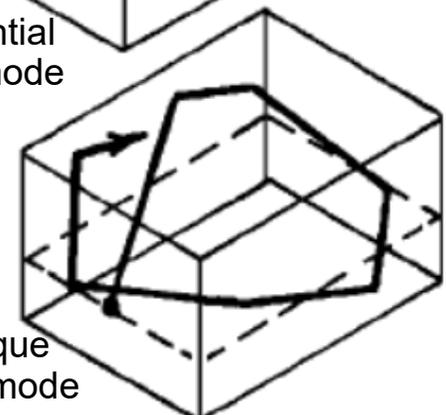
If walls (or floor and ceiling) are **parallel** facing each other, sound waves are reflected **several times** between them. Directly at the **walls** there is always a **pressure maximum**. The pressure maxima and minima of these sound waves always remain in the **same place**; the wave seems to stand.



Axial
room mode



Tangential
room mode



Oblique
room mode



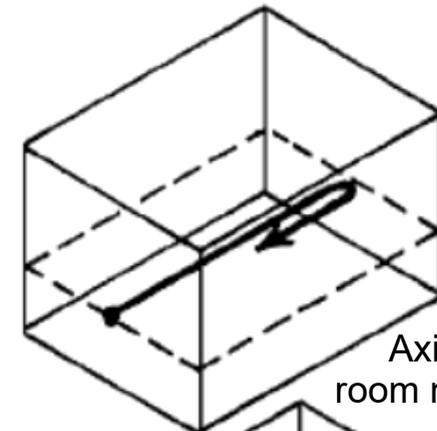
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1.3 Room Modes (Standing Waves)

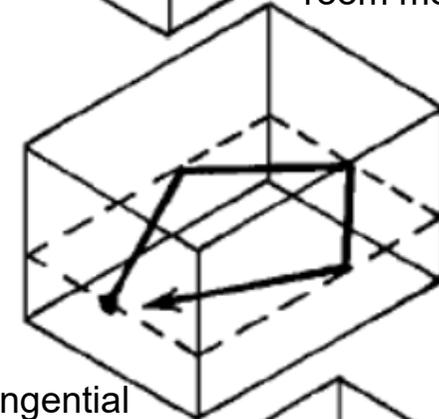
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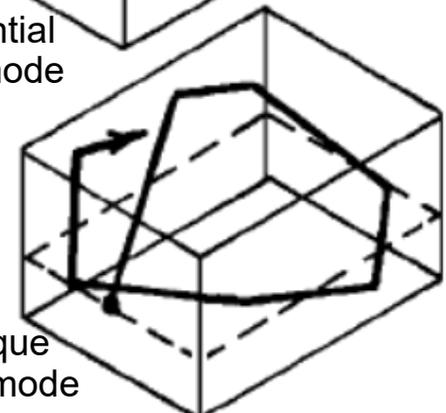
Standing waves **should be avoided** as far as possible, as they cause that in some places in the room the sound is **particularly loud** and in other places **very quiet**.



Axial
room mode



Tangential
room mode



Oblique
room mode

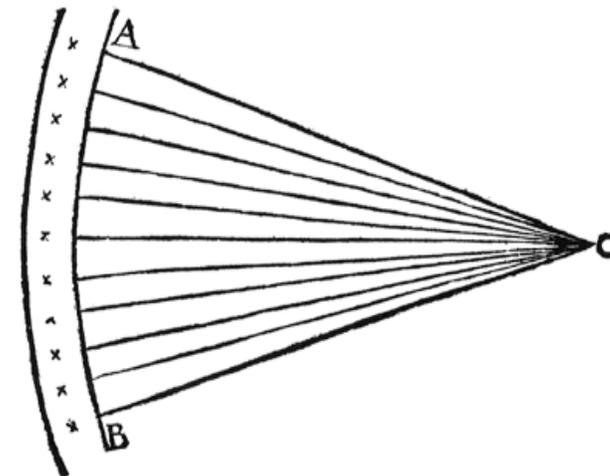


Reflection gives Satisfaction

1.4 Reflections on curved Surfaces

For reflections on curved surfaces, the **concave mirror laws** apply. There is a risk of a **focal point formation** here, i.e. an **acoustic oversupply**.

*Sünffter Lehr-Satz. Propositio V.
Wann der widerhallende Gegenstand eine hohle Zirckul-Kundung
hat; so wird in der Stimm-Mitte oder centro, so auch des Zirckuls
centrum ist / der Echo am stärcksten und hellesten
gehöret werden,*



Reflection at the circular arc,
source is in the center of the circle
(Kircher 1684 p. 17)



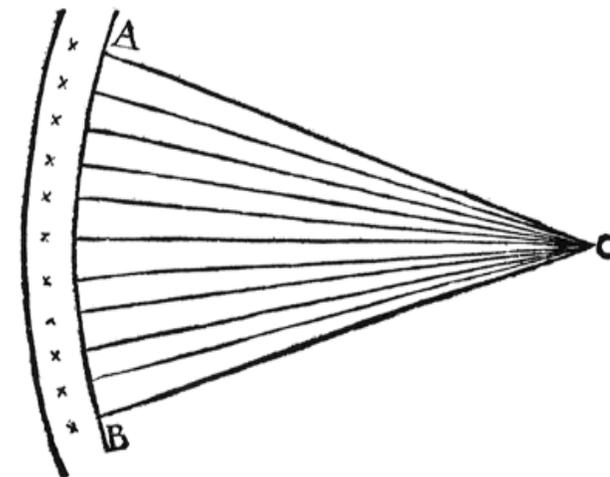
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1.4 Reflections on curved Surfaces

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Is the source exactly in the **center** of the circle, the focal point will be there as well.

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Reflection gives Satisfaction

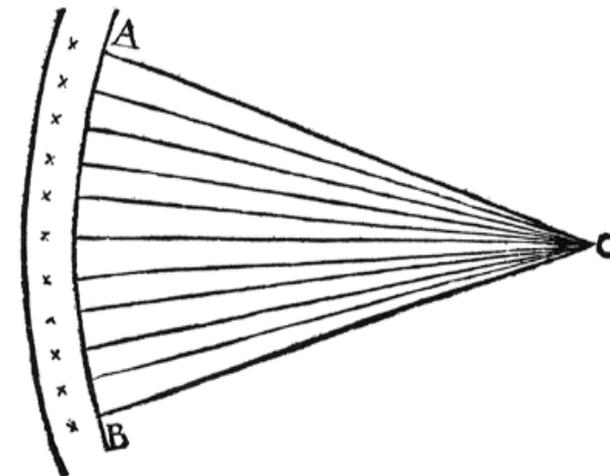
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For reflections on curved surfaces, the **concave mirror laws** apply. There is a risk of a **focal point formation** here, i.e. an **acoustic oversupply**.

Is the source exactly in the **center** of the circle, the focal point will be there as well.

If the source **moves out of the center** of the circle, then the focal point is shifted in the **opposite direction**.

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Wann der widerhallende Gegenstand eine hohle Zirckul-Kundung
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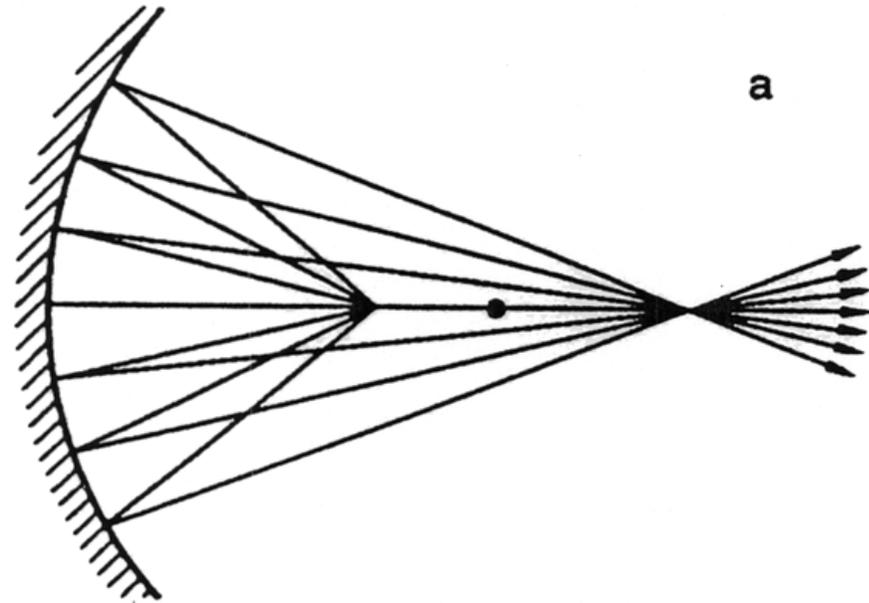


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1.4 Reflections on curved Surfaces

Elliptical Reflection:

If the source is **near the center** of the circle, the focal point is located at the **opposite side** of the center



Elliptical Reflection at the circular arc,
source is between the circular wall
and the center of the circle
(Meyer 2015, p. 146)

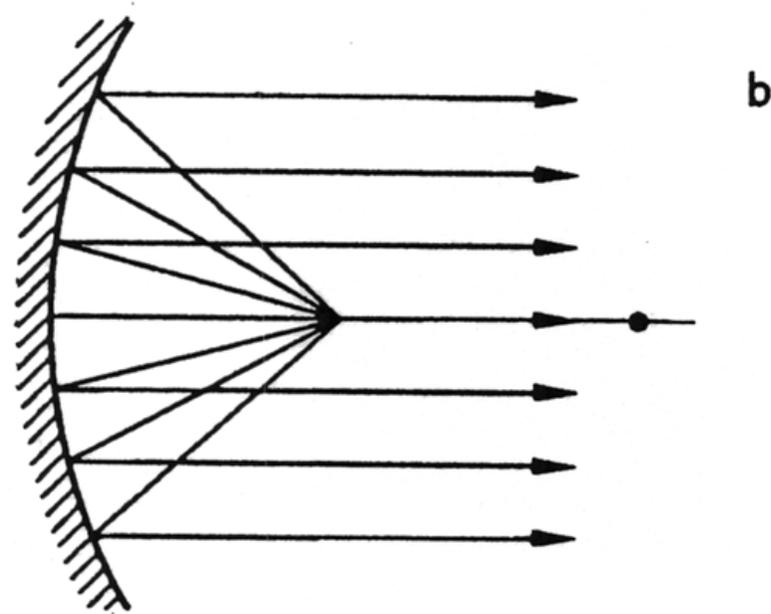


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1.4 Reflections on curved Surfaces

Parabolic Reflection:

If the source is exactly located **between** the center of the circle and the circle, wall **no focal point** formation will occur, the sound rays proceed in **parallels**.



Parabolic Reflection at the circular arc,
source is exactly between the circular wall
and the center of the circle
(Meyer 2015, p. 146)



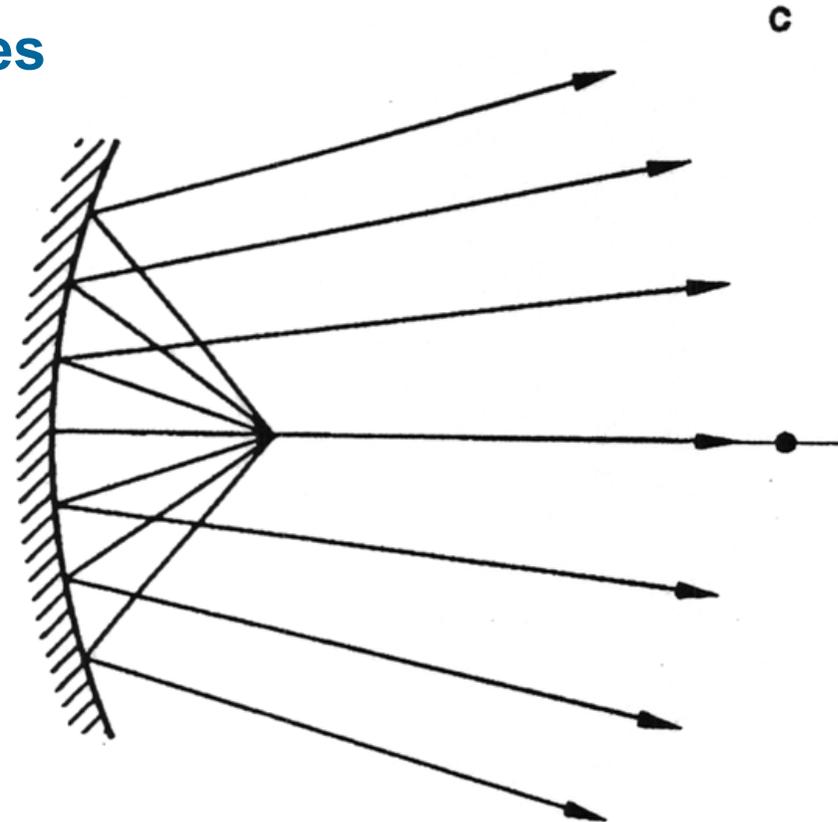
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1.4 Reflections on curved Surfaces

Hyperbolic Reflection:

If the source is **close to** the circular wall, there is **no focal point** formation.

The rays behave **like a hyperbolic reflection on a convex surface** and split apart.



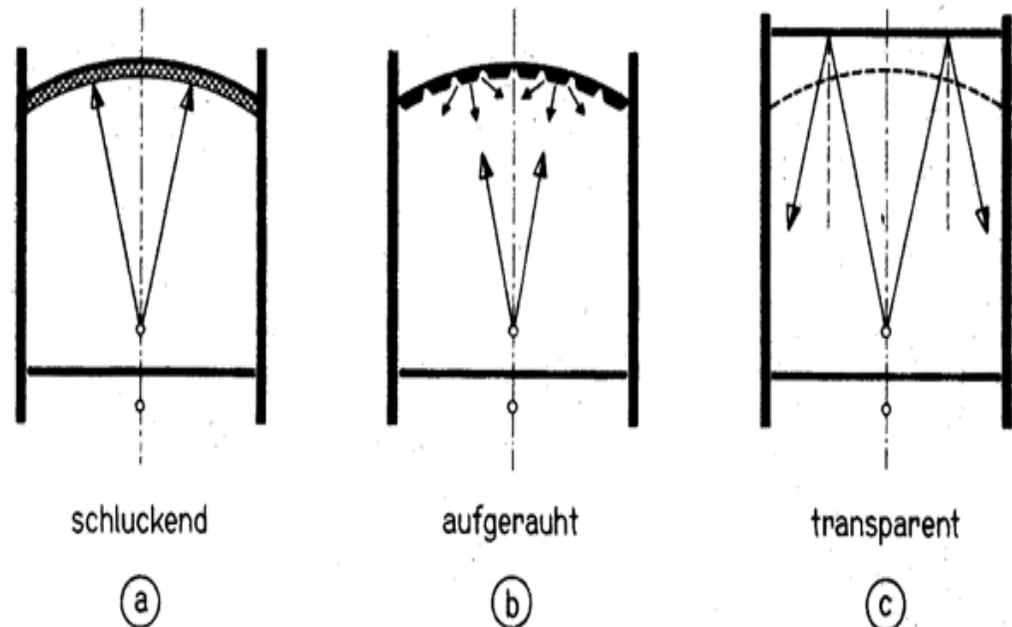
Hyperbolic Reflection at the circular arc,
source is close to the circular wall
and far away from the center of the circle.
(Meyer 2015, p. 146)



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1.4 Reflections on curved Surfaces

How to avoid focal points?



Avoidance of focus point formation at curved surfaces
(Cremer 1978, p. 48)



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1.4 Reflections on curved Surfaces

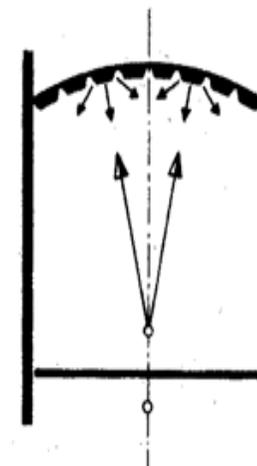
How to avoid focal points?

a) Covering the curved surface with **sound-absorbing materials**.



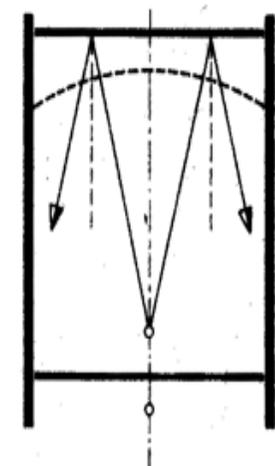
schluckend

(a)



aufgerauht

(b)



transparent

(c)

Avoidance of focus point formation at curved surfaces
(Cremer 1978, p. 48)



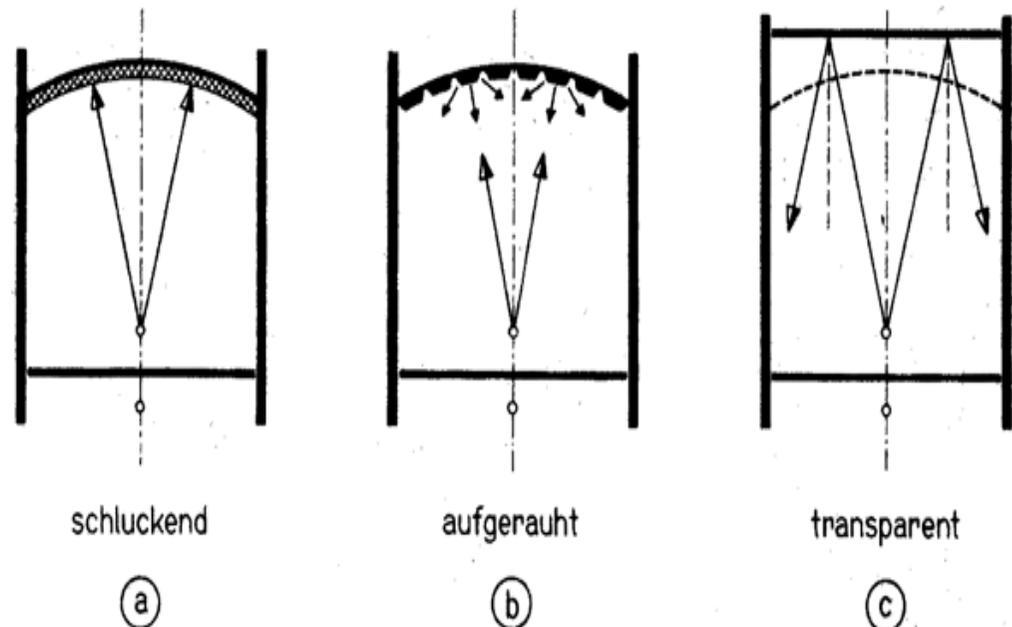
Reflection gives Satisfaction

1.4 Reflections on curved Surfaces

How to avoid focal points?

a) Covering the curved surface with **sound-absorbing materials**.

b) Covering the curved surface with **convex structures**.



Avoidance of focus point formation at curved surfaces
(Cremer 1978, p. 48)



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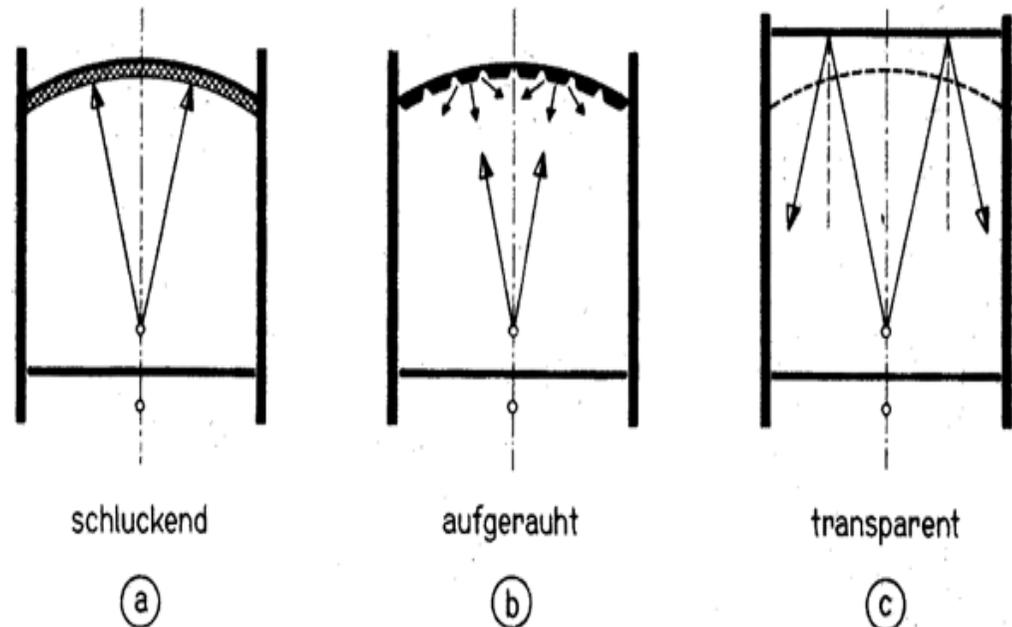
1.4 Reflections on curved Surfaces

How to avoid focal points?

a) Covering the curved surface with **sound-absorbing materials**.

b) Covering the curved surface with **convex structures**.

c) **Permeable** concave curved surface (wire mesh, perforated walls) with a straight, roughened, **convex** and / or **absorbent surface** behind.



Avoidance of focus point formation at curved surfaces
(Cremer 1978, p. 48)



Reflection gives Satisfaction

Take Home Message

The **path of a soundwave** can be considered as a **sound ray**.

Angle of incidence = Angle of reflection

Reflection is dependent of the **wavelength** and the **size of the reflecting surface**:

Wavelength is **smaller** than the reflecting surface: **reflection**

Wavelength is **larger** than the reflecting surface: **no reflection**

Room modes (standing waves) = Room **resonances**, where the **wavelength** (or multiples of it) fits into a **room distance**, should be **avoided**

Concave mirror laws apply for reflections on **curved surfaces**.
Focal points should be **avoided**.



Reflection gives Satisfaction

1.5 Interfering vs. Useful Reflections

Interfering Reflections = **Echo**

Strong audible and dominant single reflection which occurs with delays of **more than 100 ms** between direct sound and reflected sound (corresponding to a path difference of more than **34 m** or 17 m forth and 17 m back).



Reflection gives Satisfaction

1.5 Interfering vs. Useful Reflections

Interfering Reflections = **Echo**

Strong audible and dominant single reflection which occurs with delays of **more than 100 ms** between direct sound and reflected sound (corresponding to a path difference of more than **34 m** or 17 m forth and 17 m back).

An **echo** is perceived **separately** from the original sound (as above our **perception time smear of 50 ms**) and therefore usually perceived as **interfering sound**.



Reflection gives Satisfaction

1.5 Interfering vs. Useful Reflections

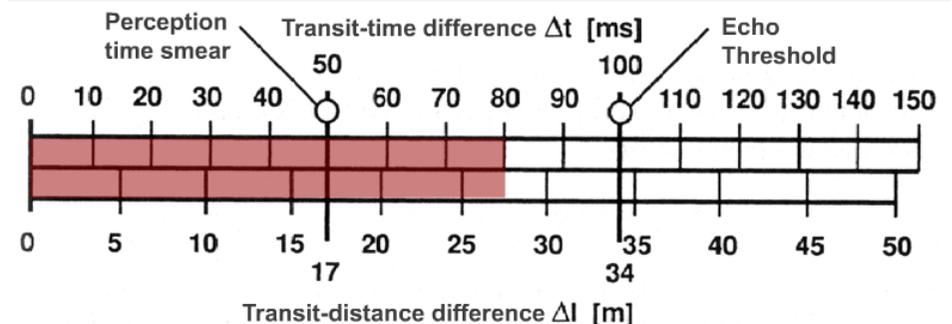
Interfering Reflections = Echo

Strong audible and dominant single reflection which occurs with delays of **more than 100 ms** between direct sound and reflected sound (corresponding to a path difference of more than **34 m** or 17 m forth and 17 m back).

An **echo** is perceived **separately** from the original sound (as above our **perception time smear of 50 ms**) and therefore usually perceived as **interfering sound**.

Useful Reflections = Amplification

Early reflections (**less than 50 ms**) are perceived as blended with the original sound, which gives a **reinforced impression** of the sound (corresponding to a path difference of less than **17 m** or 8,5 m forth and 8,5 m back).



[Time and path differences in room acoustics](#)
(after Fasold, Veres 2003, p. 53)



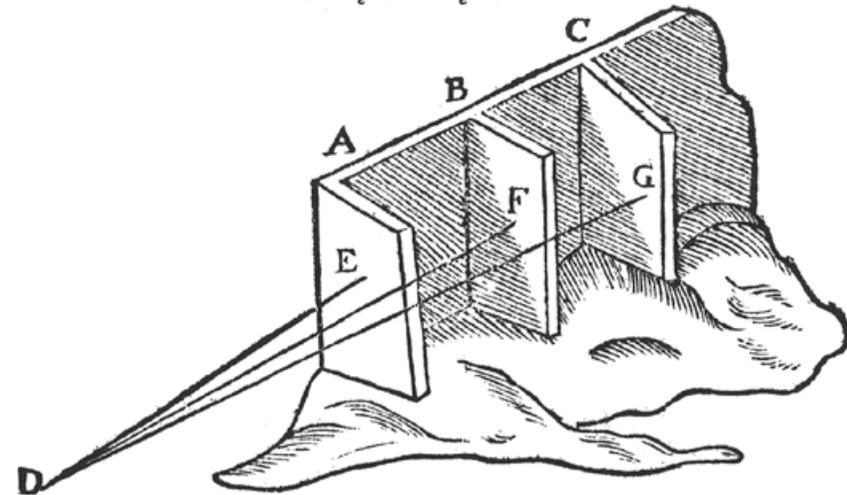
Reflection gives Satisfaction

1.5 Interfering vs. Useful Reflections

Echoes arise preferably:

Eibender Lehr=Saß. Propositio VII.

Wann sich mehrere gegen=hallende objecta und Vorstände finden /
daß immer einer weiter von dem andern / und derowegen die gerade Stimme oder
Ehon / langsamer zu den hindersten kommet ; so wird dannenher ein vielstimmiger
Echo sich hören lassen / so den Ehon oder Stimm nach und nach
immer mehr wider=hallen wird.



Echo effect at different distances
(Kircher 1684, p. 19)



Reflection gives Satisfaction

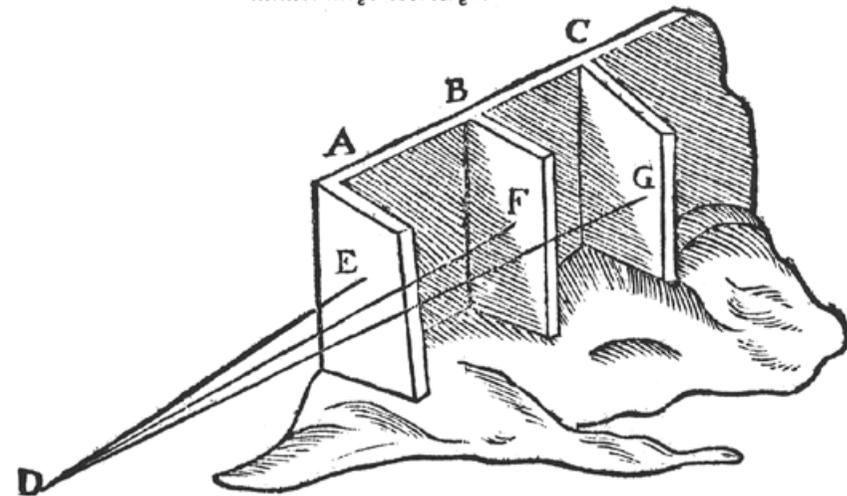
1.5 Interfering vs. Useful Reflections

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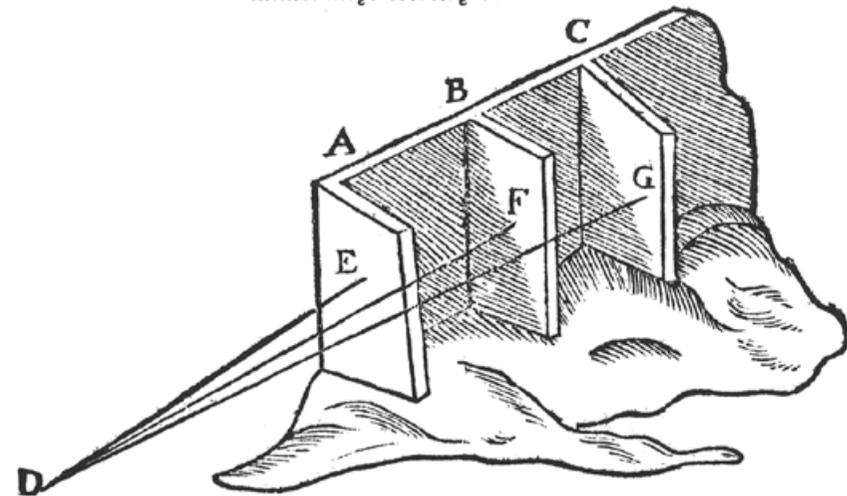
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- In rooms with partially **sound-absorbing** or **concavely curved walls** (focal points)

Eibender Lehr-Satz. Propositio VII.

Wann sich mehrere gegenhallende objecta und Vorstände finden / daß immer einer weiter von dem andern / und derowegen die gerade Stimme oder Ehon / langsamer zu den hindersten kommet ; so wird dannenher ein vielstimmiger Echo sich hören lassen / so den Ehon oder Stimm nach und nach immer mehr widerhallen wird.



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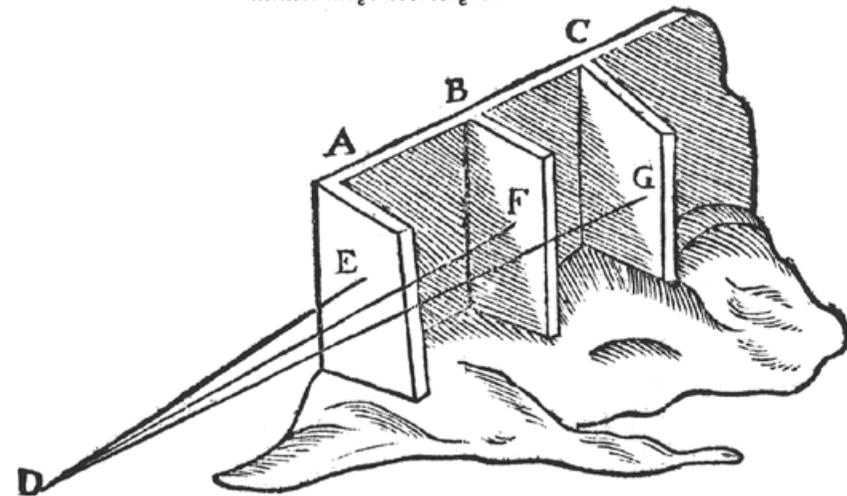
1.5 Interfering vs. Useful Reflections

Echoes arise preferably:

- **Outdoors** (as there are not many other reflections, so a reflection is more often easy to hear individually)
- In rooms with partially **sound-absorbing** or **concavely curved walls** (focal points)
- In **theaters**, often in case of strong reflections on the back wall or the ceiling (so-called **theater echo**)

Eibender Lehr-Satz. Propositio VII.

Wann sich mehrere gegenhallende objecta und Vorstände finden /
daß immer einer weiter von dem andern / und deswegen die gerade Stimme oder
Ehon / langsamer zu den hindersten kommet ; so wird dannenher ein vielstimmiger
Echo sich hören lassen / so den Ehon oder Stimm nach und nach
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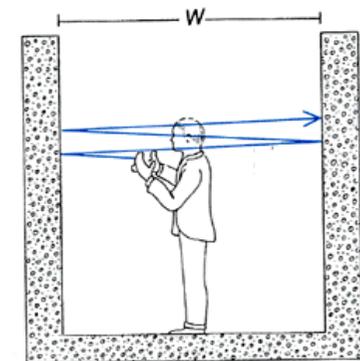
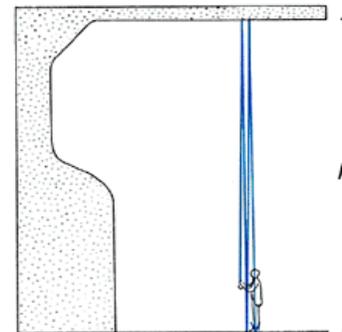
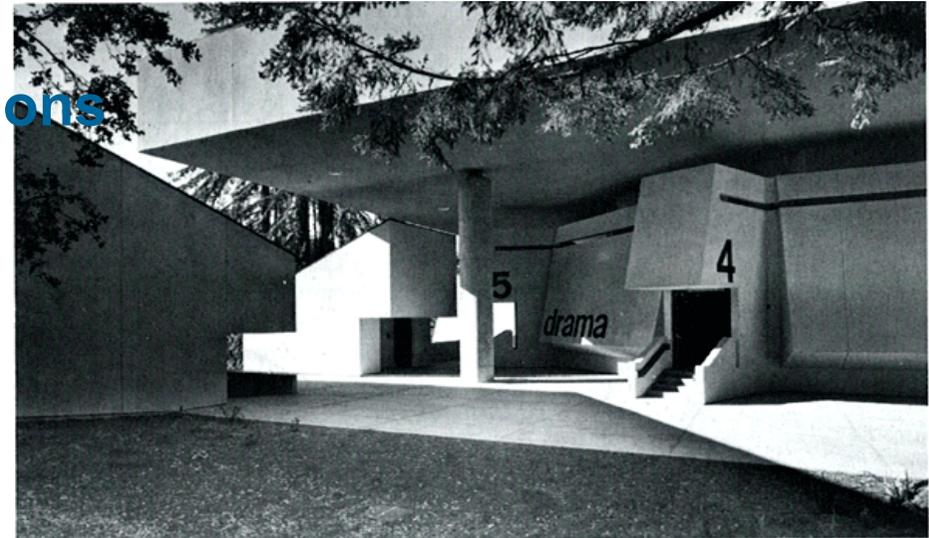


Reflection gives Satisfaction

1.5 Interfering vs. Useful Reflections

Flutter echo (or **timbre echo**):

Periodic echo caused by **alternating reflections** between two parallel walls.



Flutter echos under a roof ledge on the grounds of the University of California in Santa Cruz (Pierce 1999, p. 27)



Reflection gives Satisfaction

1.5 Interfering vs. Useful Reflections

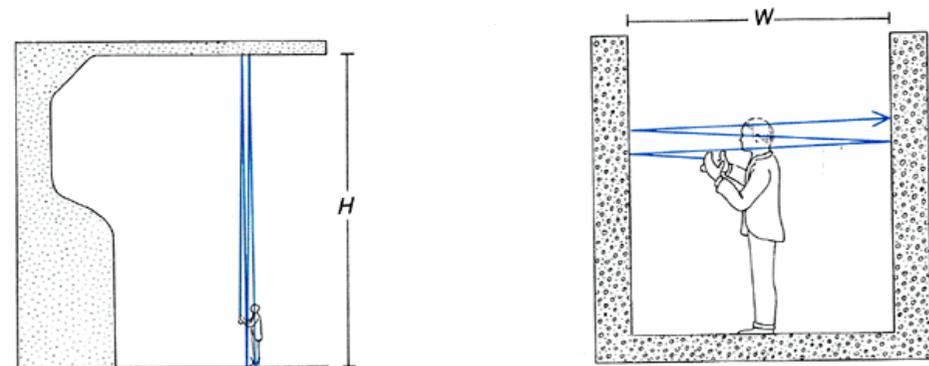
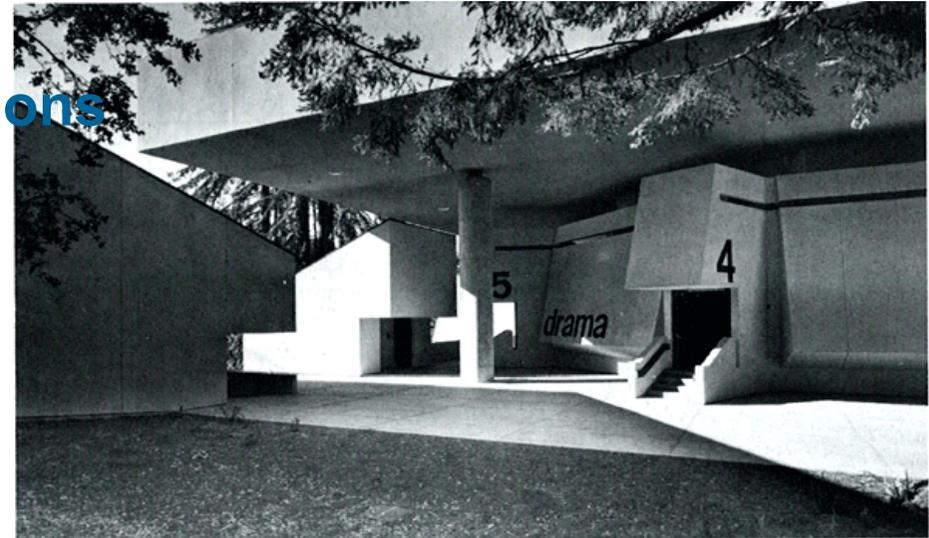
Flutter echo (or **timbre echo**):

Periodic echo caused by **alternating reflections** between two parallel walls.

This occurs often in tunnels or stairways, when two highly reflective walls face each other in parallel or between floor and ceiling.

[Impulse response in the Schlüterhof of the German Historical Museum \(DHM\) in Berlin](#)

[Youtube 360°-Video: Flutter echo in the Viennese Gasometer](#)



Flutter echos under a roof ledge on the grounds of the University of California in Santa Cruz (Pierce 1999, p. 27)



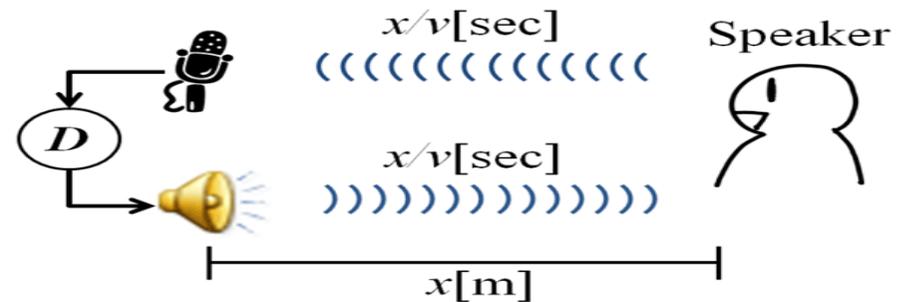
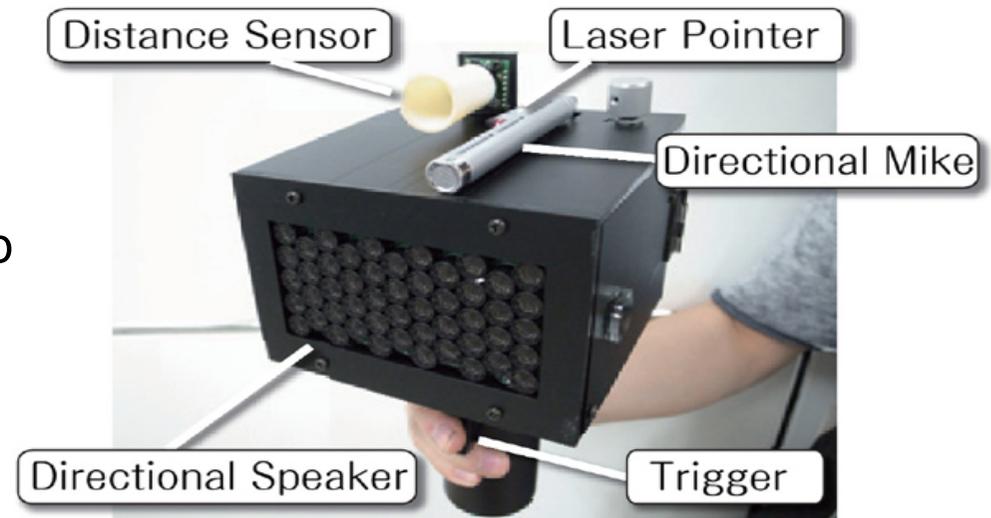
Reflection gives Satisfaction

1.5 Interfering vs. Useful Reflections

Generation of artificial interfering echoes with via a Speechjammer

The talk of a speaker can be picked up from a distance via a **directional microphone** and, after a **short delay**, returned to him/her with pinpoint accuracy via a **directional loudspeaker**, so that only he/her can hear these artificial, confusing **echoes**, which causes him/her to stop talking.

Fun Fact 😊



Speechjammer (Kurihara, Tsukada 2012, p. 6)



Reflection gives Satisfaction

Take Home Message

Interfering Reflections (perceived as **echo**) occur with **delays** of **more than 100 ms** (\triangleq more than **34 m**) between direct sound and reflected sound, should be **avoided**.

Useful Reflections (perceived as **amplification**) occur with **delays** of **less than 50 ms** (\triangleq less than **17 m**) between direct sound and reflected sound, should be **aimed at**.

Flutter Echo = alternating reflections between two **parallel walls**, should be **avoided**.

By **changing the tilt** of **walls/ceiling/reflectors** etc. it is possible to **direct** interfering sound rays to **useful reflections**.

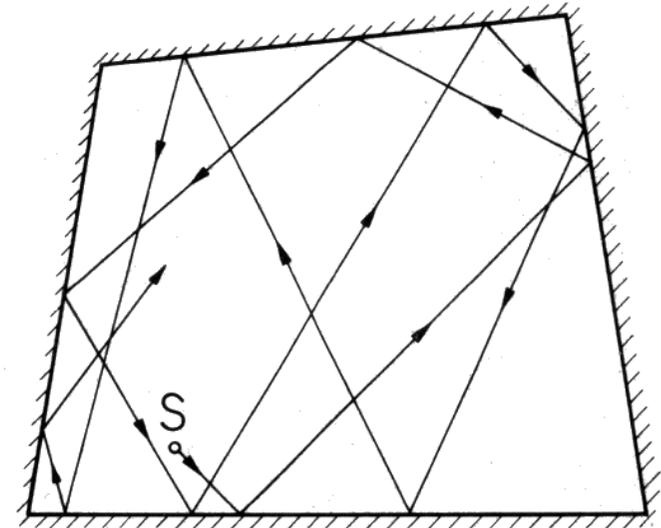


Reflection gives Satisfaction

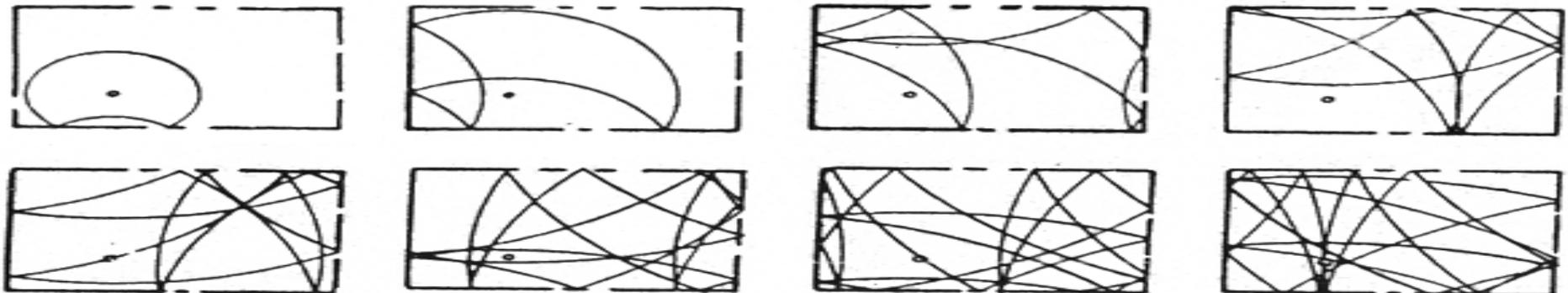
2. Statistical Acoustics

All rooms limited by large straight surfaces lead to an equal distribution of sound rays after a few reflections (i.e. diffuse = **statistically distributed sound field**).

They also lead to an omnidirectional sound distribution, if opposed parallel walls with similar surfaces are avoided (-> reverberation).



Reflections inside an oblique-angled room (Cremer 1948, p. 26; Cremer 1978, p. 29)



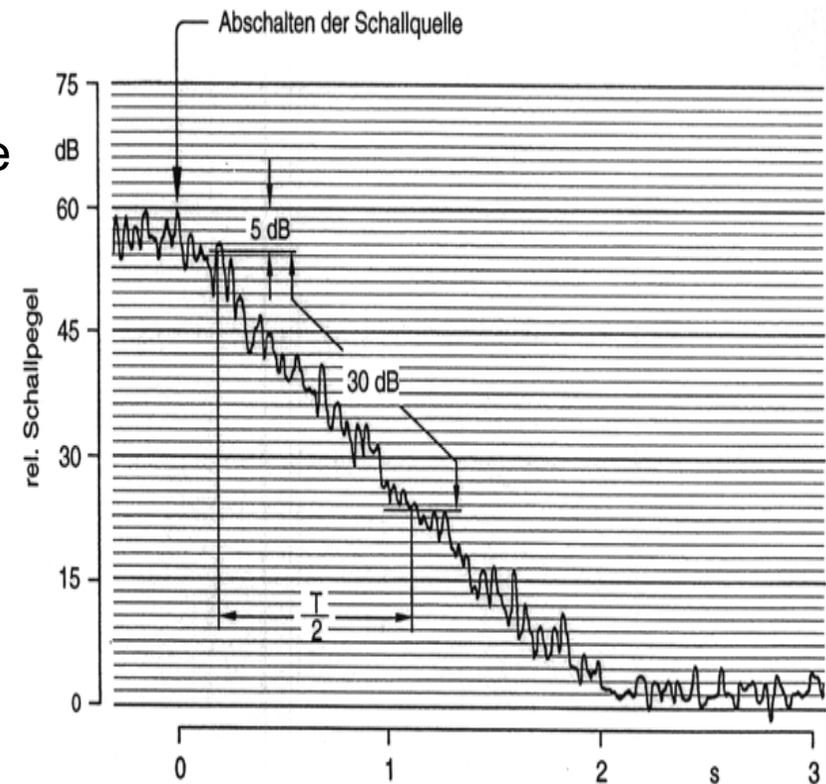
Sound propagation and reflexions inside a rectangular room (Cremer 1948, p. 22; Cremer 1978, p. 25)



Reflection gives Satisfaction

2.1 Audibility and Reverberation

Audibility: **Suitability** of a room for music and voice performances is determined by the nature and duration of the **reverberation** (other factors are: type of sound sources, style of music, location, subjective hearing).





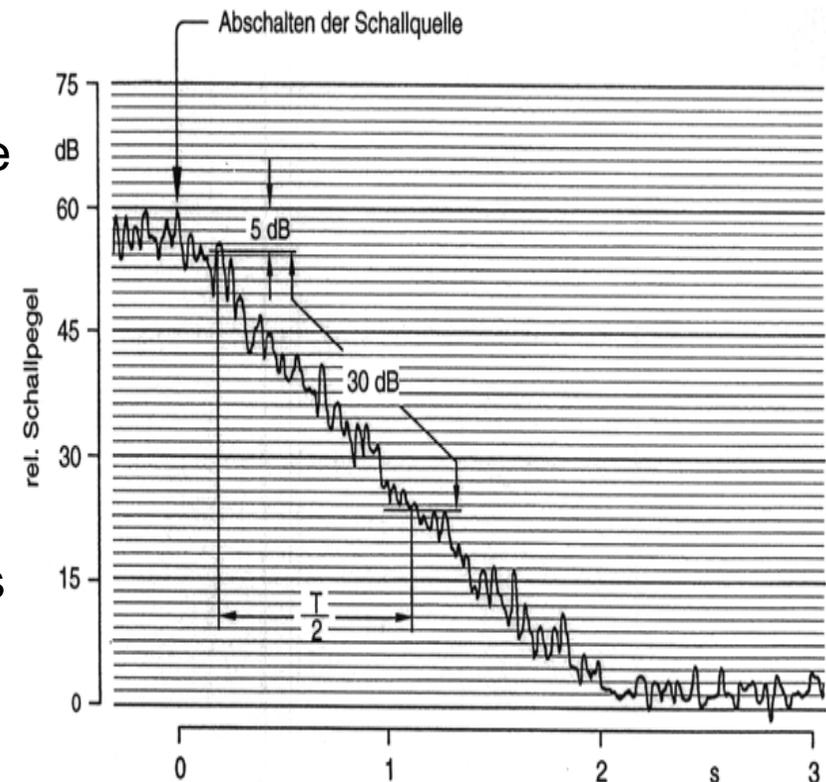
Reflection gives Satisfaction

2.1 Audibility and Reverberation

Audibility: **Suitability** of a room for music and voice performances is determined by the nature and duration of the **reverberation** (other factors are: type of sound sources, style of music, location, subjective hearing).

Reverberation time (RT_{60}) = time after switching off the sound source until the sound level has decreased by 1 million times (i.e. **-60 dB**).

Mostly the decreasing time to **30 dB** gets measured and the result is doubled (**RT_{30}** , from -5 dB to -35 dB)



Measurement of the reverberation time
 RT_{30} on a level recorder
(Meyer 2015, p.149)



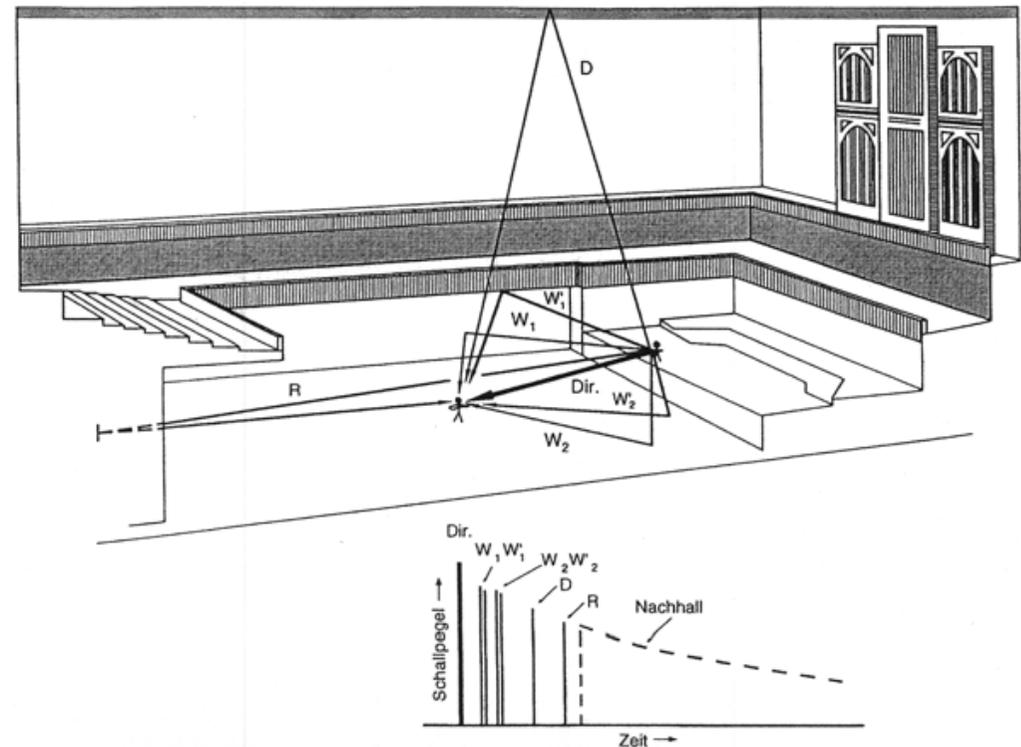
Reflection gives Satisfaction

2.1 Audibility and Reverberation

As a sound source for attaining the **reverberation time**, **pistol** shots or bursting **balloons** or a **flap** are very suitable.

- [Balloon burst caused by a needle](#)
- [Balloon burst caused by too much blowing up](#)
- [Pistol shot](#)
- [Slap of a flap](#)

Highspeed videos with 5000 frames/s,
playback speed: 5 frames/s
(recording: Jörg Mühlhans)



Emerging of a reverberation
from a lot of individual reflections
(Meyer 2015, p. 156)



Reflection gives Satisfaction

2.2 The Sabine Formula

The reverberation time and its nature is influenced by the **rooms volume (V)** and the **absorption (A)** of the different surfaces in the room.



Reflection gives Satisfaction

2.2 The Sabine Formula

The reverberation time and its nature is influenced by the **rooms volume (V)** and the **absorption (A)** of the different surfaces in the room.

Equivalent Absorption Surface (A) = Model surface, which indicates how much sound energy is absorbed in a room.

The **Reverberation time (T_s)** can be calculated (at low absorbance values) using the **Sabine reverberation formula** over the equivalent absorption surface:

$$T_s = 0,163 * V / A$$

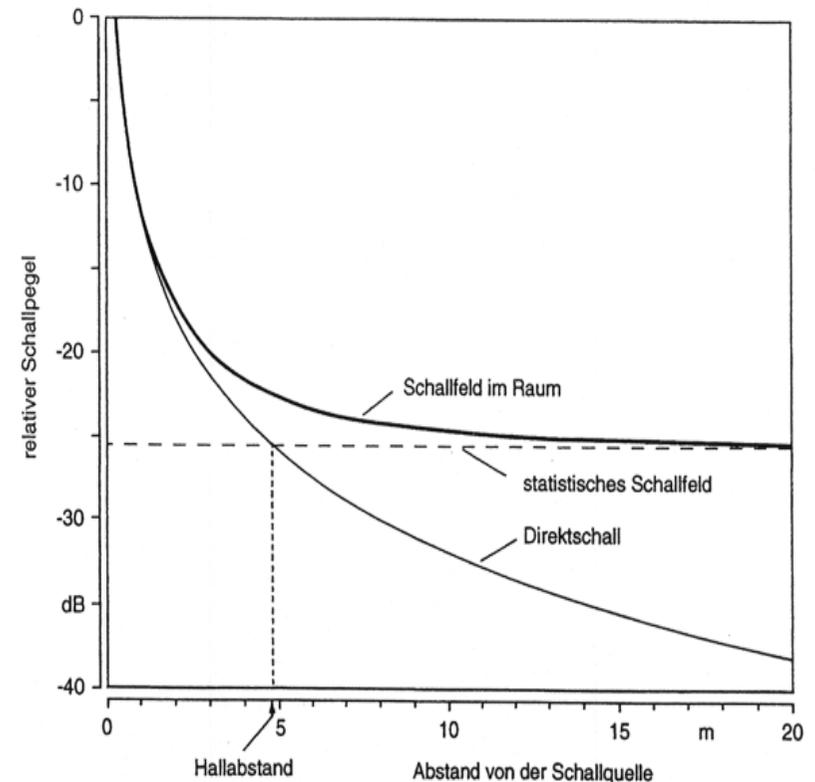
(Reverberation time (T_s) = 0,163 * room volume (V) divided by equivalent absorption surface (A))



Reflection gives Satisfaction

2.3 Critical Distance

Critical Distance: distance from the sound source, where the **reverberation intensity** is just as large as the **direct sound intensity**.



Sound level as a function of the distance in the diffuse and free sound field
(Meyer 2015, p. 152)

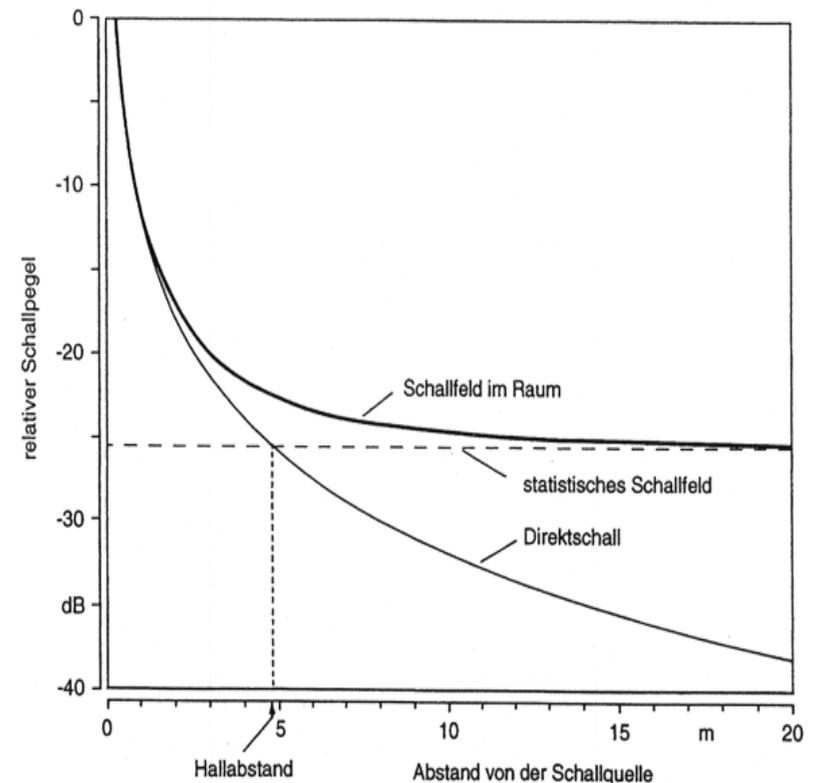


Reflection gives Satisfaction

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Critical Distance: distance from the sound source, where the **reverberation intensity** is just as large as the **direct sound intensity**.

Inside critical distance: Original sound level decreases by -6dB per doubling distance (like in a free sound field).



Sound level as a function of the distance in the diffuse and free sound field (Meyer 2015, p. 152)



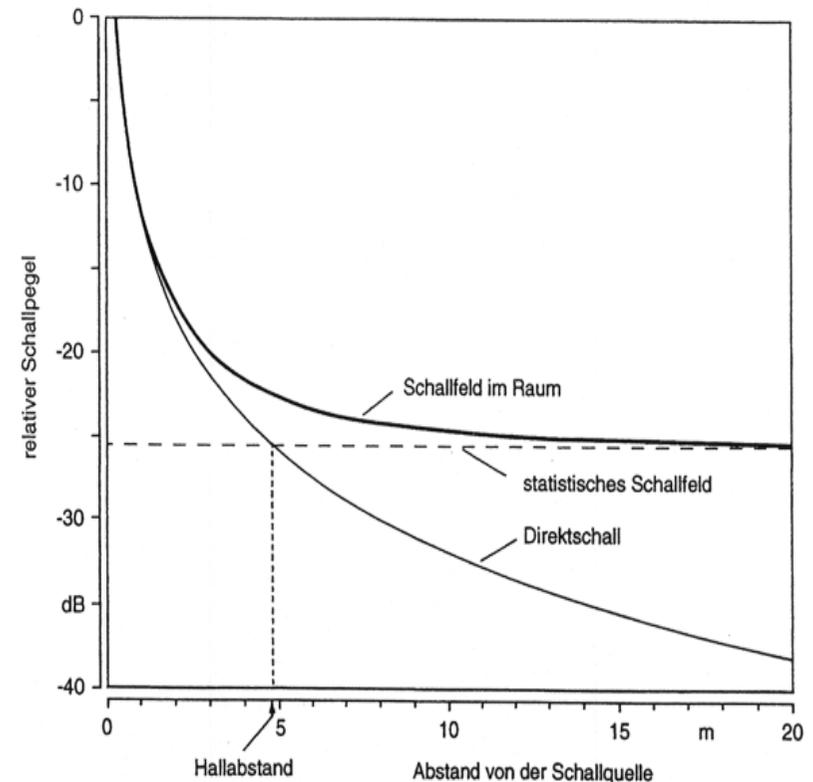
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Sound level as a function of the distance in the diffuse and free sound field (Meyer 2015, p. 152)



Reflection gives Satisfaction

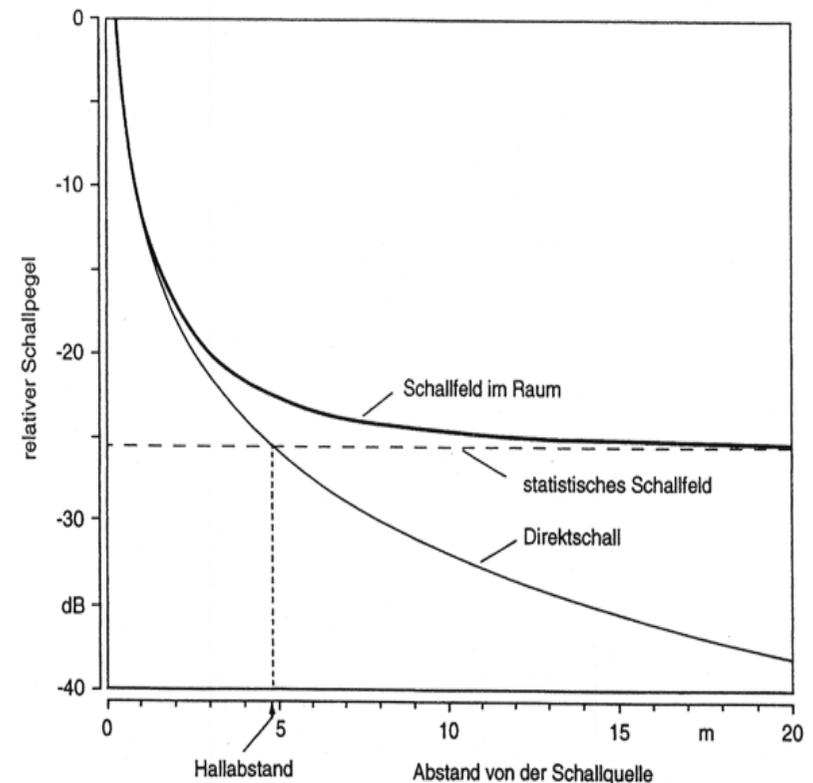
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Inside critical distance: Original sound level decreases by -6dB per doubling distance (like in a free sound field).

At critical distance: sound level is as high as the reverberation level.

Outside critical distance: Reverberation level gets higher than the level of the original sound. The sound source becomes more and more incomprehensible.



Sound level as a function of the distance in the diffuse and free sound field (Meyer 2015, p. 152)



Reflection gives Satisfaction

2.4 Further Characteristics of Audibility

2.4.1 Speech and Music Clarity Indices

Speech Clarity Index C_{50}

measures the **intelligibility** of syllables, logatoms, and sentence for speech and vocal performances, described by the speech clarity index C_{50} .

(Measurements are mostly between 500 and 4000 Hz)

$$c_{50} = 10 * \left(\lg \frac{\int_0^{50\text{ms}} p^2(t) dt}{\int_{50\text{ms}}^{\infty} p^2(t) dt} \right) \text{dB}$$

The sound energy arriving within **50 ms**
is compared with the sound energy **arriving later**.



Reflection gives Satisfaction

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Music Clarity Index C_{80}

measures the **transparency** or clarity for musical performances, described by the music clarity index C_{80}

$$c_{80} = 10 * \left(\lg \frac{\int_0^{80\text{ms}} p^2(t) dt}{\int_{80\text{ms}}^{\infty} p^2(t) dt} \right) \text{dB}$$

The sound energy arriving within **50** or **80 ms** is compared with the sound energy **arriving later**.



Reflection gives Satisfaction

2.4 Further Characteristics of Audibility

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**Optimum:
-2 to +4 dB**

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**Optimum:
-1 to +3
dB**

The sound energy arriving within **50** or **80 ms** is compared with the sound energy **arriving later**.



Reflection gives Satisfaction

2.4 Further Characteristics of Audibility

2.4.2 Bass Ratio and Strength

Bass Ratio (BR) (Beranek 1962)

Frequency response of reverberation (ratio of **high to low frequencies** in reverberation). The **Bass Ratio** describes the **timbre** of room reverberation. It increases with increasing audience (high frequencies get more absorbed then)

$$BR = \frac{T_{125\text{Hz}} + T_{250\text{Hz}}}{T_{500\text{Hz}} + T_{1000\text{Hz}}}$$

Ratio of the reverberation times at frequencies at 125 Hz and 250 Hz to frequencies at 500 Hz and 1000 Hz.
(Ahnert, Tennhardt in Weinzierl 2008, p. 191)



Reflection gives Satisfaction

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Strength G (Lehmann 1976)

Strength describes the **amplification** of the direct sound by the sum of all reflections. A good strength causes the impressions of "**intimacy**" and "**closeness**" of a room.

$$G = 10 \lg \frac{\int_0^{\infty} p^2(t) dt}{\int_0^{10\text{ms}} p_F^2(t) dt} \quad \text{dB}$$

Ratio of the sound power level in the room compared to the sound power level at a distance of 10m in free field
(Ahnert, Tennhardt in Weinzierl 2008, p. 191)



Reflection gives Satisfaction

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**Optimum:
1,1 to 1,3**

Ratio of the reverberation times at frequencies at 125 Hz and 250 Hz to frequencies at 500 Hz and 1000 Hz. (Ahnert, Tennhardt in Weinzierl 2008, p. 191)

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**Optimum:
1 to 10 dB**

Ratio of the sound power level in the room compared to the sound power level at a distance of 10m in free field (Ahnert, Tennhardt in Weinzierl 2008, p. 191)



Reflection gives Satisfaction

2.4 Further Characteristics of Audibility

2.4.3 Lateral Fraction

Lateral Fraction (LF)

describes the ratio of **laterally arriving sound energy to total energy** within the first 80 ms after the arrival of direct sound. It gives an impression of **spaciousness**.

$$LF = \frac{(W_{5 \dots 80 \text{ ms}})_{\text{seitl.}}}{W_{0 \dots 80 \text{ ms}}}$$

Ratio of laterally incident sound energy (recorded 5-80 ms after the beginning of the sound with a bidirectional microphone) to the sound energy within the first 80 ms
(Ahnert, Tennhardt in Weinzierl 2008, p. 191)



Reflection gives Satisfaction

2.4 Further Characteristics of Audibility

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describes the ratio of **laterally arriving sound energy to total energy** within the first 80 ms after the arrival of direct sound. It gives an impression of **spaciousness**.

**Optimum:
0,25 to 0,4**

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Ratio of laterally incident sound energy (recorded 5-80 ms after the beginning of the sound with a bidirectional microphone) to the sound energy within the first 80 ms
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Reflection gives Satisfaction

Take Home Message

Audibility = **Suitability** of a room for music and voice performances, mainly determined by **reverberation**

Reverberation time (RT_{60}) = time after switching off the sound source until the sound level decreases to **-60 dB**

Sabine reverberation formula: $T_s = 0,163 * V / A$

(Reverberation time (T_s) = 0,163 * room volume (V) divided by equivalent absorption surface (A))



Reflection gives Satisfaction

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(Reverberation time (T_s) = 0,163 * room volume (V) divided by equivalent absorption surface (A))

Optimum Reverberation Time (RT_{60})

RT_{60} at **opera houses**: 1 s

RT_{60} at **concert halls**: 1,6 to 2,2 s

RT_{60} at **churches**: 2,5 to 4 s

RT_{60} at **lecture halls**: 0,8 to 1 s



Reflection gives Satisfaction

Take Home Message

Audibility = **Suitability** of a room for music and voice performances, mainly determined by **reverberation**

Reverberation time (RT₆₀) = time after switching off the sound source until the sound level decreases to **-60 dB**

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(Reverberation time (T_s) = 0,163 * room volume (V) divided by equivalent absorption surface (A))

Optimum Reverberation Time (RT₆₀)

RT ₆₀ at opera houses :	1 s
RT ₆₀ at concert halls :	1,6 to 2,2 s
RT ₆₀ at churches :	2,5 to 4 s
RT ₆₀ at lecture halls :	0,8 to 1 s

Other factors (optimum values)

Speech Clarity Index C₅₀ :	-2 to +4 dB
Music Clarity Index C₈₀ :	-1 to +3 dB
Bass Ratio (BR) :	1,1 to 1,3
Strength (G) :	1 to 10 dB
Lateral Fraction (LF) :	0,25 to 0,4

謝謝



Reflection gives Satisfaction

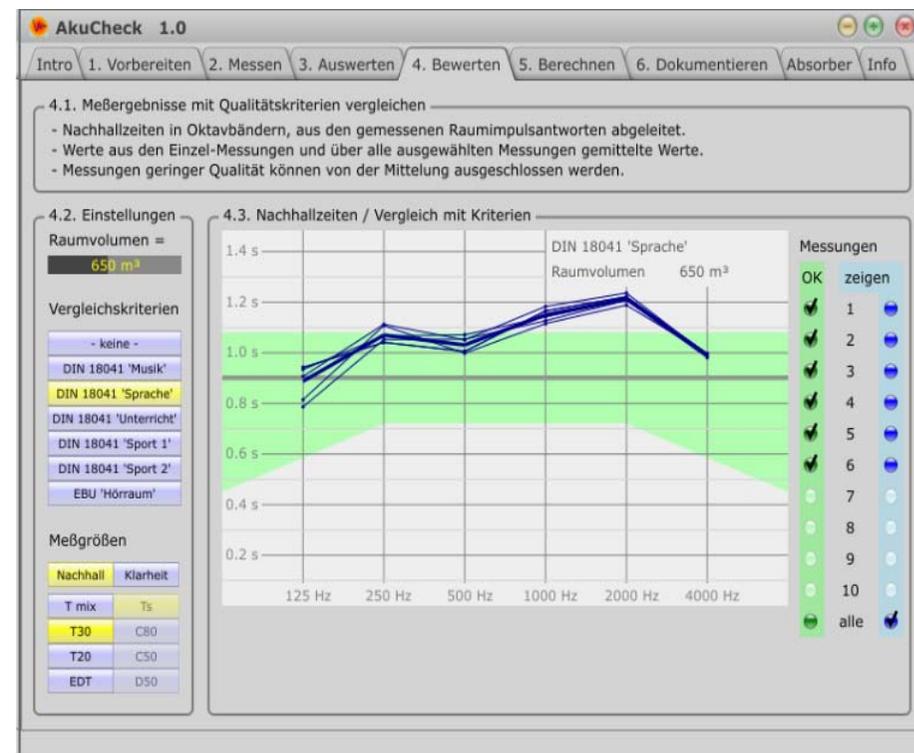
3 Live Measurement of the Lecture Room

3.1 Measurement with Akucheck

Akucheck is a room acoustics measuring program for architects. It includes a variety of comparison criteria and **industrial standards** (DIN, EBU etc.) as well as a lot of **simulation possibilities**.

It is downloadable at
<http://eclim.de/AcouCheck/index.htm>

English manual at
http://eclim.de/pub/Hennings_Voss_CESBP2013_Manuscript.pdf



Akucheck software made by Detlef Hennings (2013), <http://eclim.de/AcouCheck/index.htm>



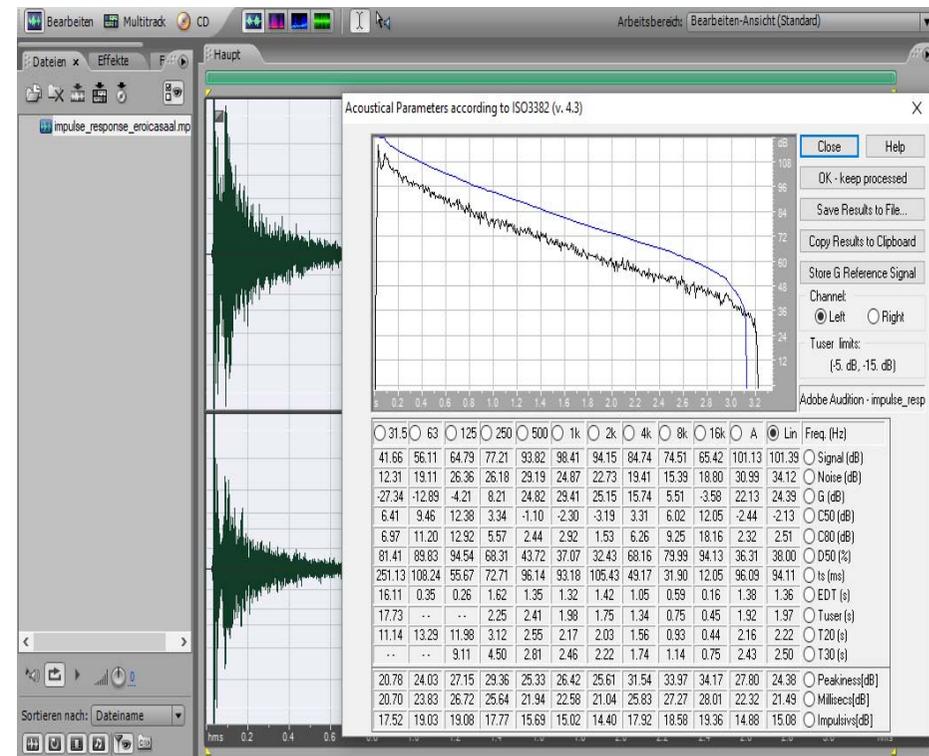
Reflection gives Satisfaction

3 Live Measurement of the Lecture Room

3.1 Measurement with Aurora/Audition

Aurora can be integrated as a plugIn in Adobe Audition and it includes various parameters of **audibility**, such as **reverberation time**, **strength**, **speech and music clarity indices** etc.

The plugIn as well as a manual is downloadable at http://pcfarina.eng.unipr.it/Aurora_XP



Aurora 4.2 made by Angelo Farina as a plugIn for Adobe Audition
http://pcfarina.eng.unipr.it/Aurora_XP