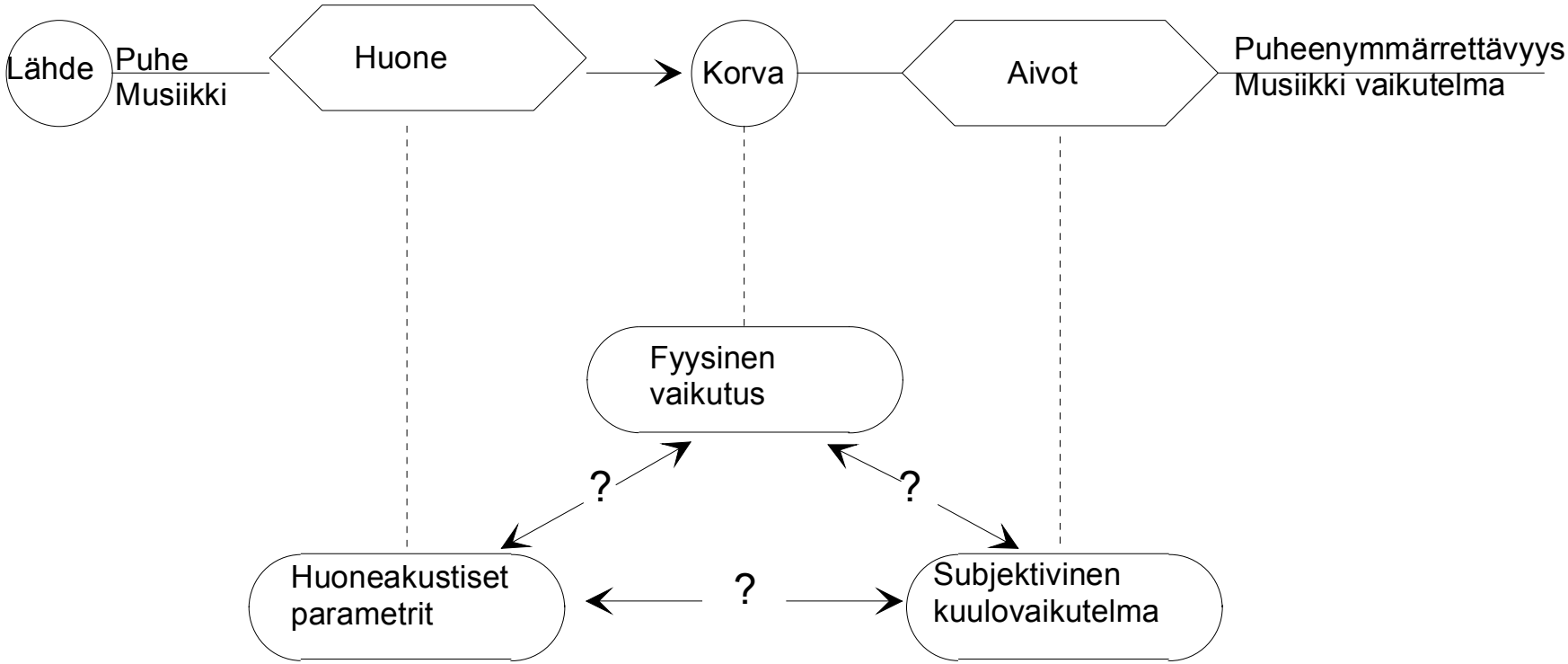
Geometric and statistical room acoustics

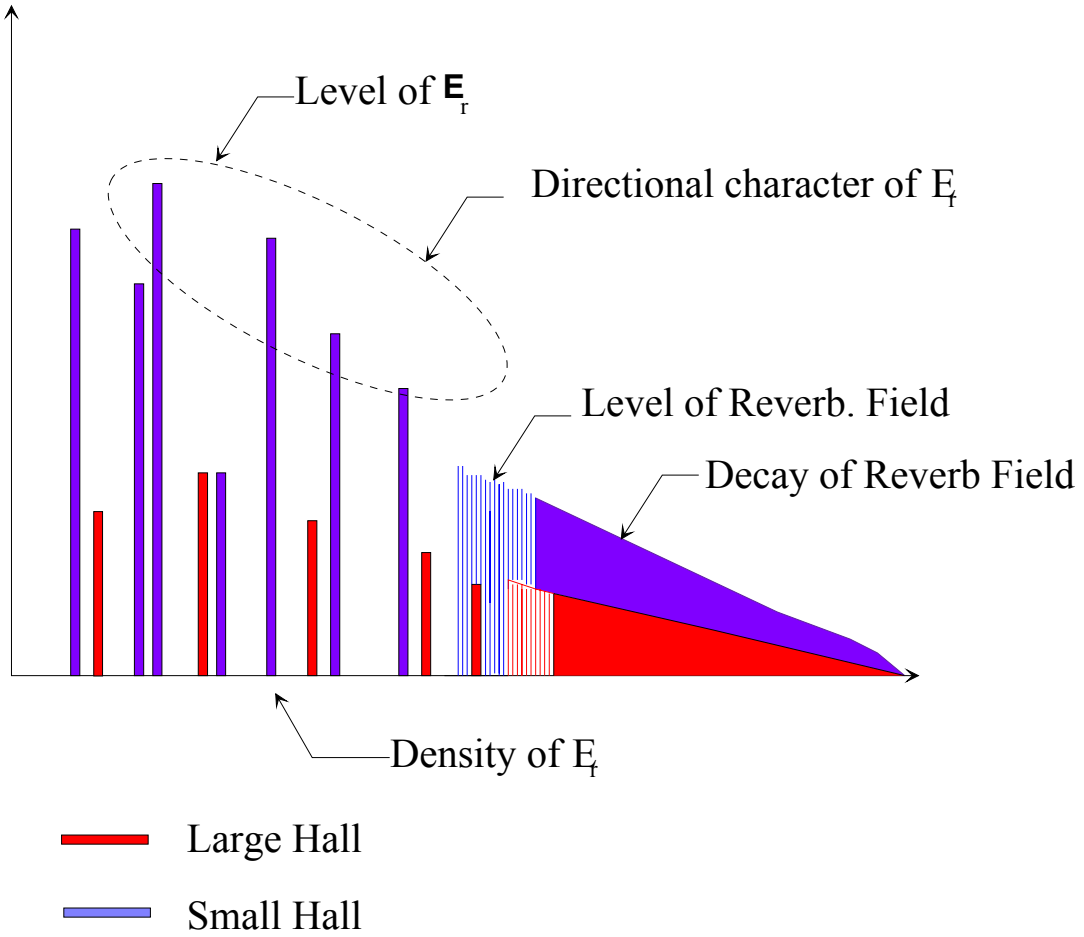
Psychology ?


Lähde
Puhe
Musiikki
Huone
Korva
Aivot
Puheenymmärrettävyys
Musiikki vaikutelma
Fyysinen
vaikutus
?
?
Huoneakustiset
parametrit
?
Subjektivinen
kuulovaikutelma

Subjective descriptors of concert hall acoustics

- Spaciousness and envelopment
- Warmth
- Reverberation or Liveliness
- Intimacy
- Acoustic glare
- Balance and blend
- Ensemble and support
- Brilliance
- Loudness
- Clarity
- Background noise level

Small vs large hall ?



Reverberation time: Sabines formular

$$R_{T60} = \frac{0{,}161V}{A + 4mV}$$

$$A = \sum \alpha * S$$

Reverberation time, m-factors

Temperature	**Humidity**	**2 000 Hz**	**4 000 Hz**	**8 000 Hz**
20°C	30 %	0,012	0,038	0,136
20°C	50 %	0,010	0,024	0,086

Average absorbtion

Statistic calclulation

$$\overline{\alpha} = \frac{\sum_i S_i \alpha_i}{\sum_i S_i}$$

From ray-traycing

$$\overline{\alpha}' = \frac{\sum_i H_i \alpha_i}{\sum_i H_i}$$

Mean Free path

$$l = \frac{4V}{S}$$

Reverberation-time: Eyring formular

$$\mathrm{RT}_{60} = \frac{0{,}161 V}{-S \ln(1-\bar{a})}$$

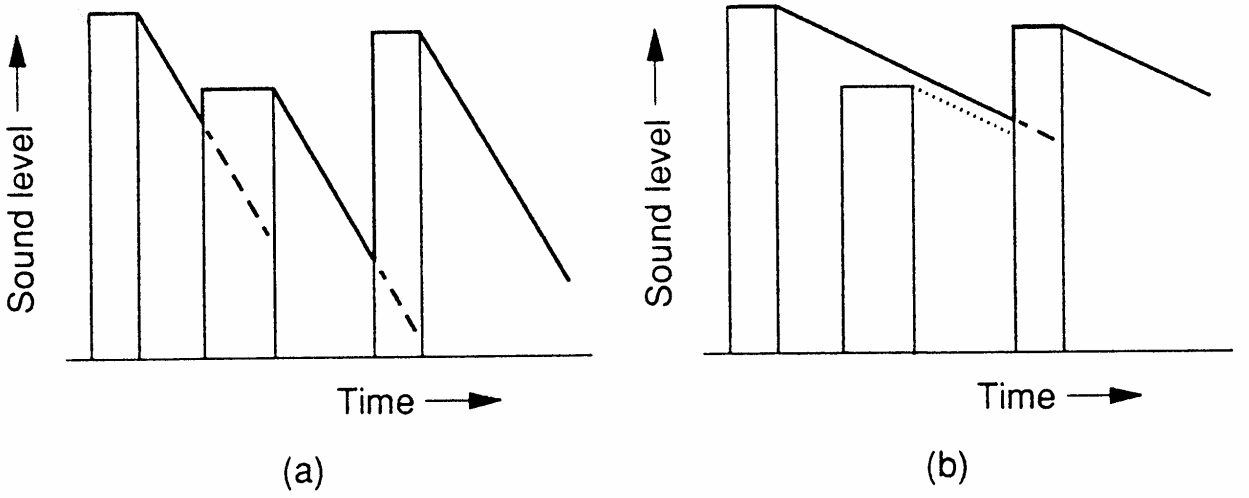
Reverberation-time: Fitzroi formular

$$RT_{60} = \frac{X}{S}\left(\frac{0{,}16V}{a_x S + 4mV}\right) + \frac{Y}{S}\left(\frac{0{,}16V}{\alpha_y S + 4mV}\right) + \frac{Z}{S}\left(\frac{0{,}16V}{\alpha_z S + 4mV}\right)$$

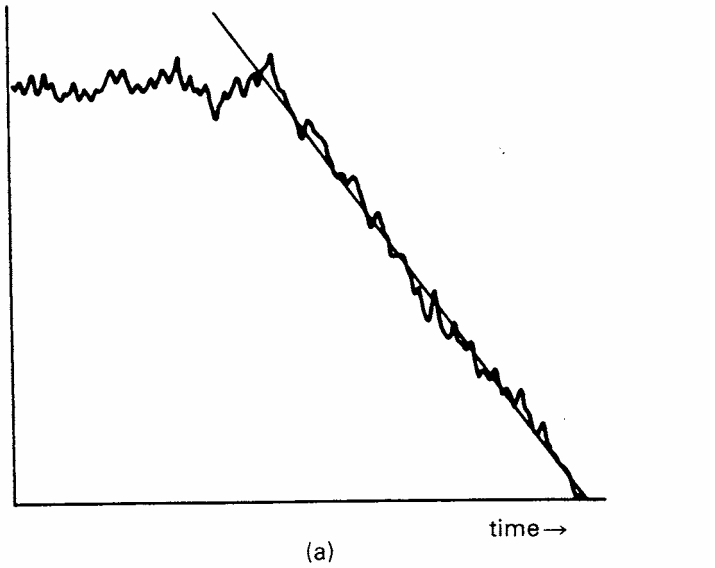
Reverberation-time: Arau-Puchades formular

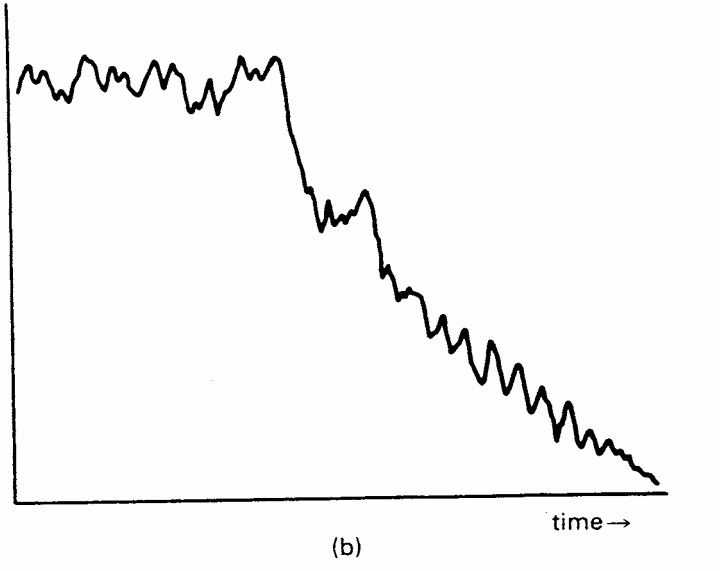
- Deducted from Fitzroi and Eyring
- Takes MFP into account

Reverberation time:

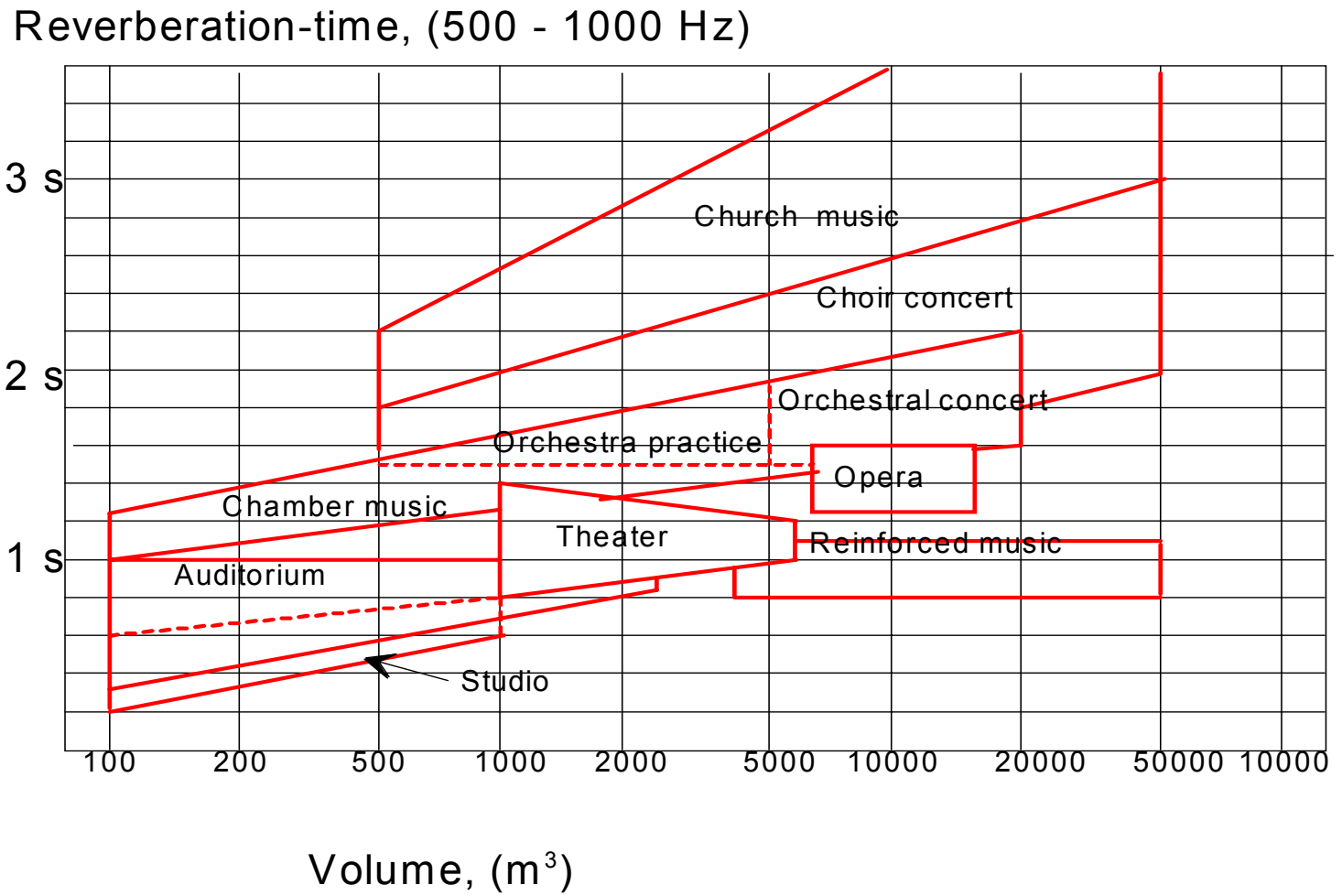


Reverberation time:





Reverberation time suggestions



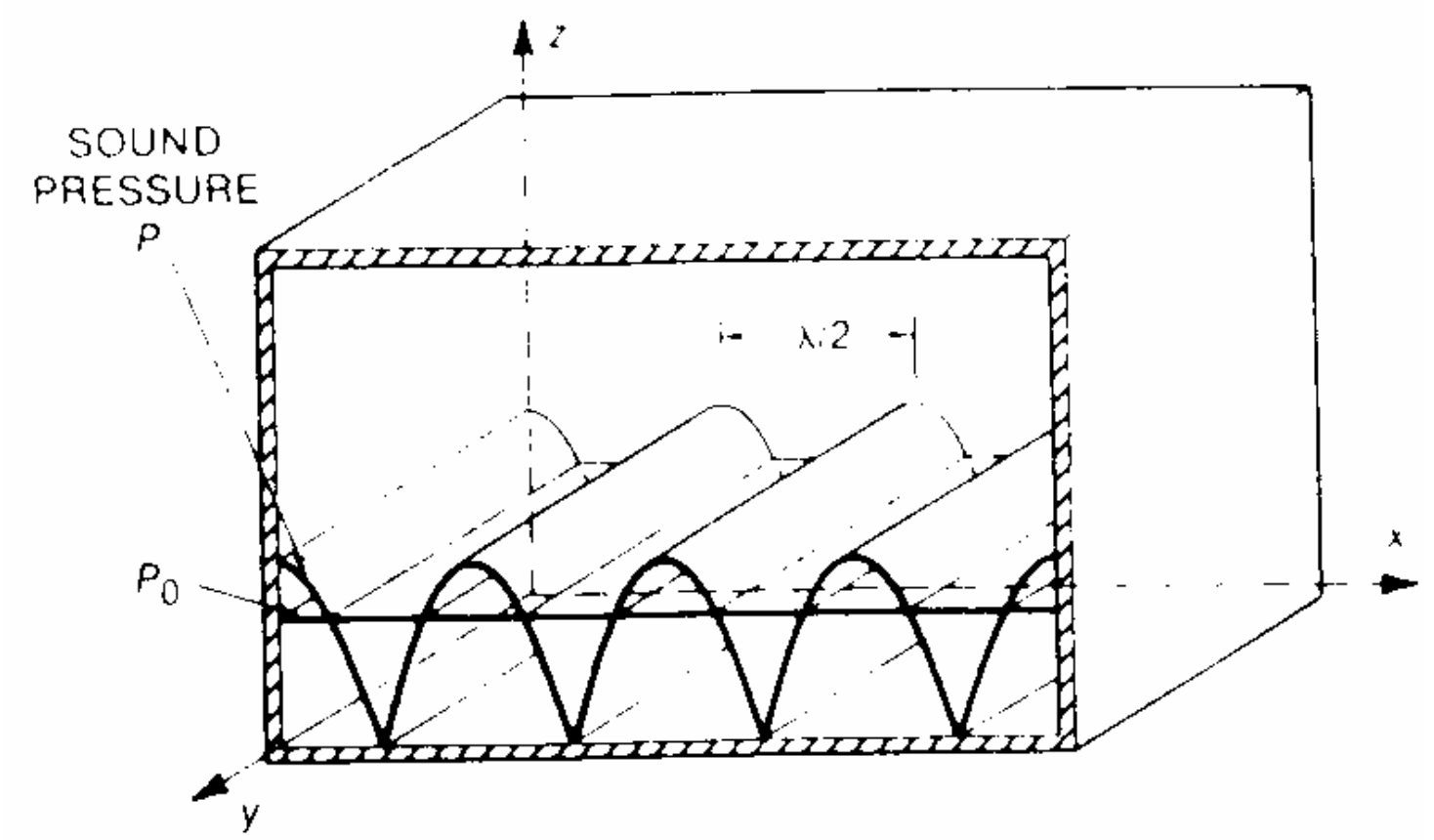
Not Reverberation

- Modes
- Flutter-echoes
- Echoes

Room modes

- ”wave fits between edges”
- Velocity minimi at edge
- Pressure maximum at edge

Room mode



Sound pressure pattern, mode (4,0,0).

Room modes: Schroeder frequency

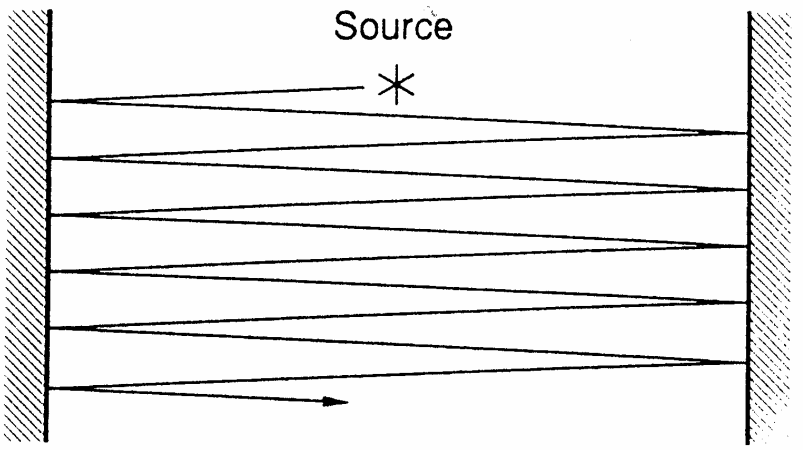
$$Fl = 2000 \cdot \sqrt{\frac{RT_{60,average}}{V}}$$

Room modes

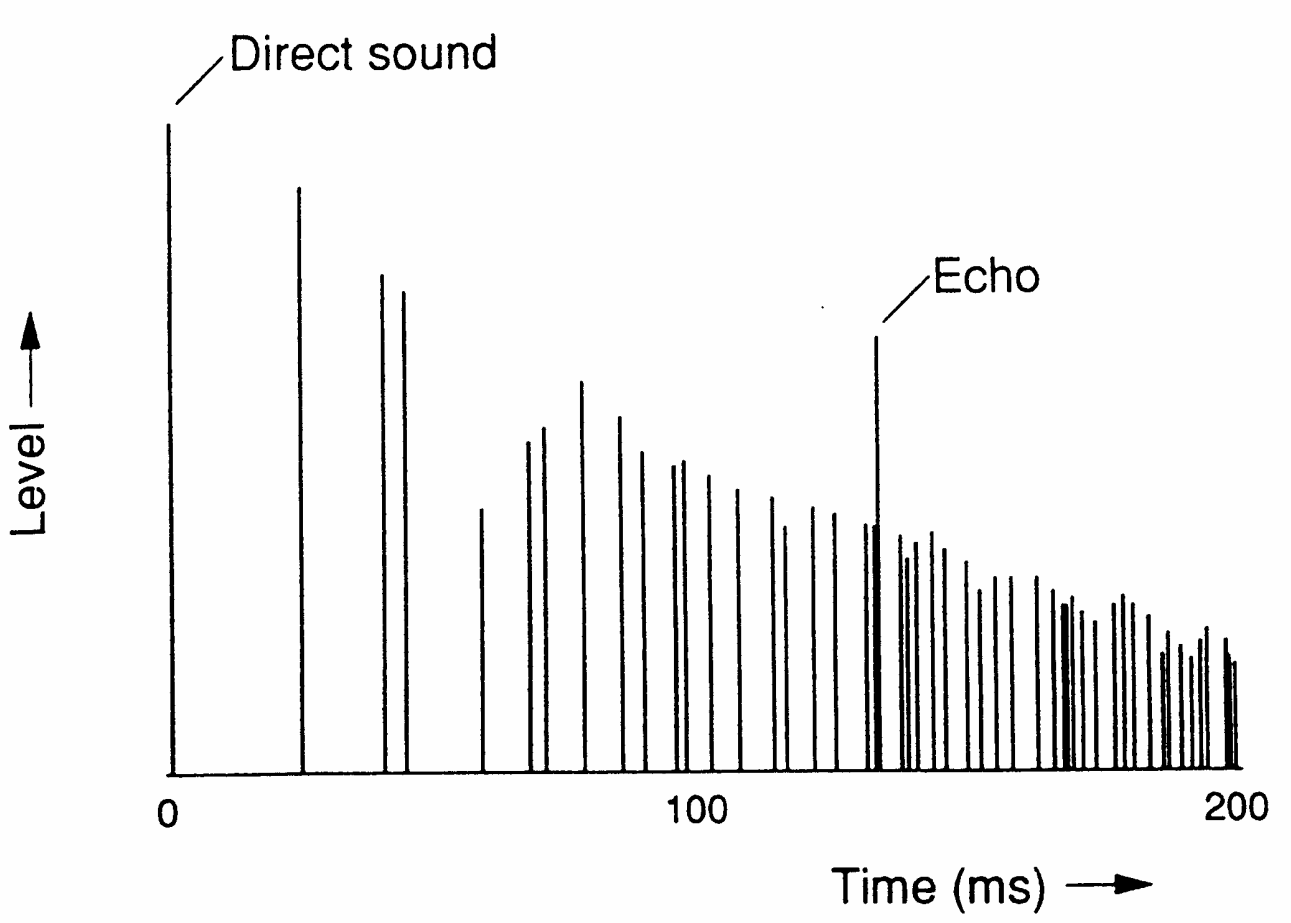
$$f_{x,y,z} = \frac{c}{2}\sqrt{\left(\frac{N_x}{L_x}\right)^2 + \left(\frac{N_y}{L_y}\right)^2 + \left(\frac{N_z}{L_z}\right)^2}$$

Where: $f_{x,y,z}$ is the mode frequency
N_x, N_y and N_z is a whole number
L_x, L_z and Lz is the resp dimentions
c is the speed of sound

Flutterecho



Echo

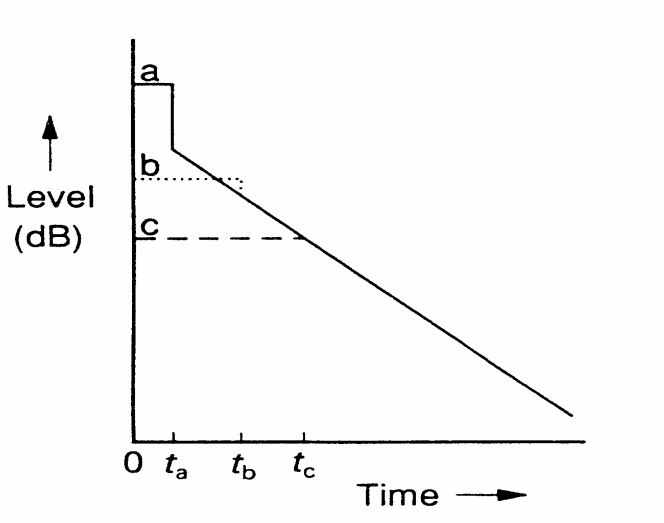


Sound levels, Classic

$$L = L_w + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4}{A}\right)$$

$$L - L_0 = 10\log\left(100/r^2 + 31200 \cdot T/V\right)$$

Sound levels: Revised theory



$$d = \frac{100}{r^2}$$

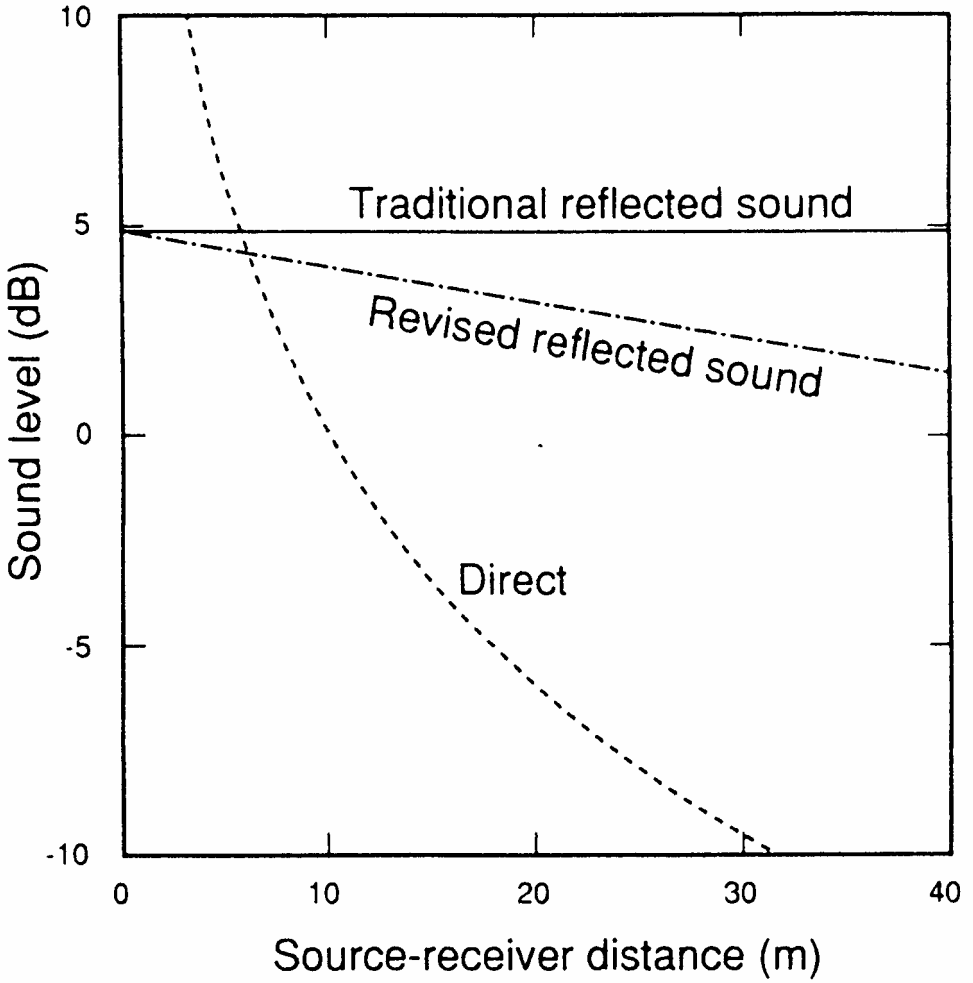
$$e_r = \left(31200 \cdot T / V\right) \cdot e^{-0{,}04 \cdot r / T} \cdot \left(1 - e^{-1{,}11/T}\right)$$

$$l = \left(31200 T / V\right) e^{-0{,}04 r / T} \cdot e^{-1{,}11/T}$$

$$L - L_0 = 10 \cdot \log\left(d + e_r + l\right)$$

$$C_{80} = 10 \cdot \log\left[\left(d + e_r\right) / l\right]$$

Sound levels: Revised theory



Reverberation

- RT_{60}
- Early Decay Time, EDT
  - Decay from 0 dB to 10 dB times 6
- Bass Ratio, BR:

$$BR = \frac{RT_{125} + RT_{250}}{RT_{500} + RT_{1000}}$$

- Treble Ratio, TR: NOTE Möllers own, not proven

Reverberation: Frequency response

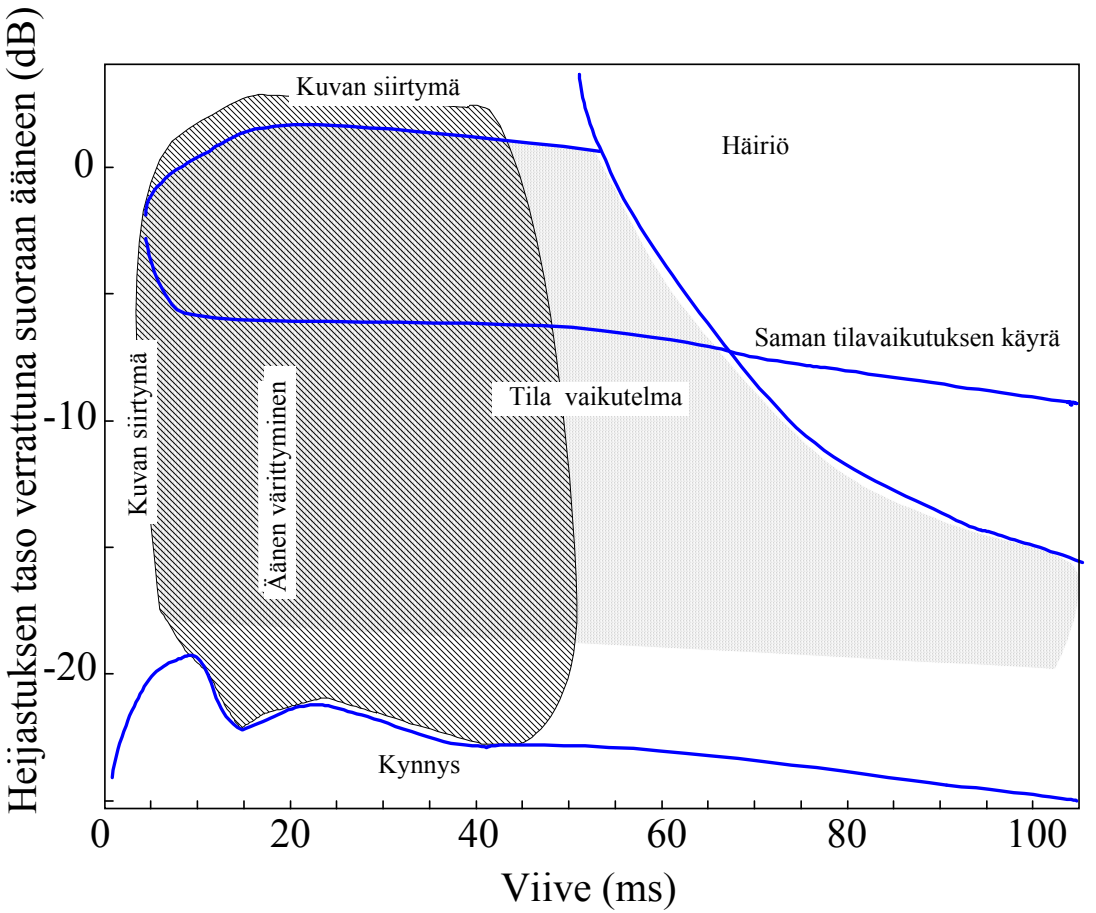
- Bass Ratio, BR:

$$BR = \frac{RT_{125} + RT_{250}}{RT_{500} + RT_{1000}}$$

- Treble Ratio, TR: NOTE Möllers own, not proven

$$TR = \frac{EDT_{2000} + EDT_{4000}}{EDT_{500} + EDT_{1000}}$$

Effect of reflections, 45° from the side



Objective descriptors: Spacial impression

$$L_{fc} = \frac{\int_{0ms}^{80ms} h^2(t)\cos(\theta)dt}{\int_{0ms}^{80ms} h^2(t)dt}$$

$$L_f = \frac{E_{fig8}(5,80ms)}{E_{omni}(0,80ms)}$$

Objective descriptors: Spacial impression

$$\Phi_{l,r}(\tau) = \frac{\int_{t_1}^{t_2} p_L(t) p_R r(t+\tau) dt}{\sqrt{\int_{t_1}^{t_2} p_L^2 dt \int_{t_1}^{t_2} p_R^2 dt}} = IACF_t(\tau)$$

$$IACC_t = \left| IACF_t(\tau) \right| \max \; for \; -1 < \tau < +1$$

$IACC_A$ is (t_1 = 0 ms, t_2 = 1000 ms
$IACC_E$ is (t_1 = 0 ms, t_2 = 80 ms
$IACC_L$ is (t_1 = 80 ms, t_2 = 1000 ms

$$BQI = \left[1 - IACC_{E3} \right]$$

Objective descriptors: Late Strength

$$\mathrm{G}_{\mathrm{l,late}} = 10\log\left(\frac{\int_{0,08}^{\infty} P_F^2(t)dt}{\int_0^{\infty} P_A^2(t)dt}\right), dB$$

Objective descriptor: Early/late ratios

Clarity:

$$C_{80} = 10Log\left(\frac{\int_{0ms}^{80ms} p^2 dt}{\int_{80ms}^{\infty} p^2 dt}\right) dB \qquad C_{80} = 10LOG\left(\frac{E(0,80ms)}{E(80,\infty ms)}\right) dB$$

Deutlichkeit or Destinctness, D_{50}:

$$D_{50} = \left(\frac{E(0,50ms)}{E(0,\infty ms)}\right)$$

Strength

$$G = \frac{\int_0^\infty p^2(t)dt}{\int_0^\infty p_{10m}^2(t)dt} => \frac{E(0,\infty)}{E_{1m}(0)} + 20 => L_{pl} - L_{pl:1m} + 20$$

Objective descriptors: Stage

Support factor or Early Support, ST1 or ST_{early}

$$ST_{early} = 10Log\left(\frac{E(20,100ms)}{E(0,10ms)}\right)dB$$

Total Support , ST_{total}

$$ST_{total} = 10Log\left(\frac{E(20,1000ms)}{E(0,10ms)}\right)dB$$

Clarity on Stage, CS

Early Decay Time on Podium, EDTP

Vocabulary

Criteria	Descriptor	
Clarity	Muddy	Clear
Reverberance	Dead	Live
Envelopment	Expansive	Constricted
Intimacy	Remote	Intimate
Loudness	Loud	Quiet
Balance: treble re mid frequencies	Weak	Loud.
Balance: bas re mid frequencies	Weak	Loud.
Balance: Singers/soloists re orchestra	Weak	Loud.

Vocabulary

Reverberance	Early Decay Time
Liveness	Early Decay Time, Reverberation Time
Fullness of tone	Reverberation time
Spaciousness,	Early Lateral Energy Fractions, InterAural-Cross-Correlation (early)
Apparent source width	Early Lateral Energy Fractions, InterAural-Cross-Correlation (early)
Envelopment	Late Lateral Energy Fractions, InterAural-Cross-Correlation (late)
Intimacy	Early Lateral Energy Fractions, InterAural-Cross-Correlation (late)
Clarity	Clarity C_{80}
Blend	Details of the initial part of the impulse response
Warmth	Strength at bass frequencies, Bass Ratio
Brilliance	Strength at high frequencies, Treble Ratio
Timbre	Frequency dependency of parameters
Stage Support	Support ST_1
Hall response	Late Support ST_{late}
Ensemble	Clarity and Early Decay Time on stage

Measurement standards

- ISO 3382:1997”Acoustics - Measurement of the reverberation time of rooms with reference to other acoustical parameters”
  - Measurement setup, number of points etc
  - Description of some of the parameters
- ”Gade”
  - Setup used in a series of measurements done by A C Gade in 1990:ies
  - Less points than ISO but same geometry in all spaces
- ISO 18233:2006 ”Acoustics — Application of new measurement methods in building and room acoustics”
  - Describes MLS and swept-sine measurements
  - Measurement theory

Gade setup

Source Positions

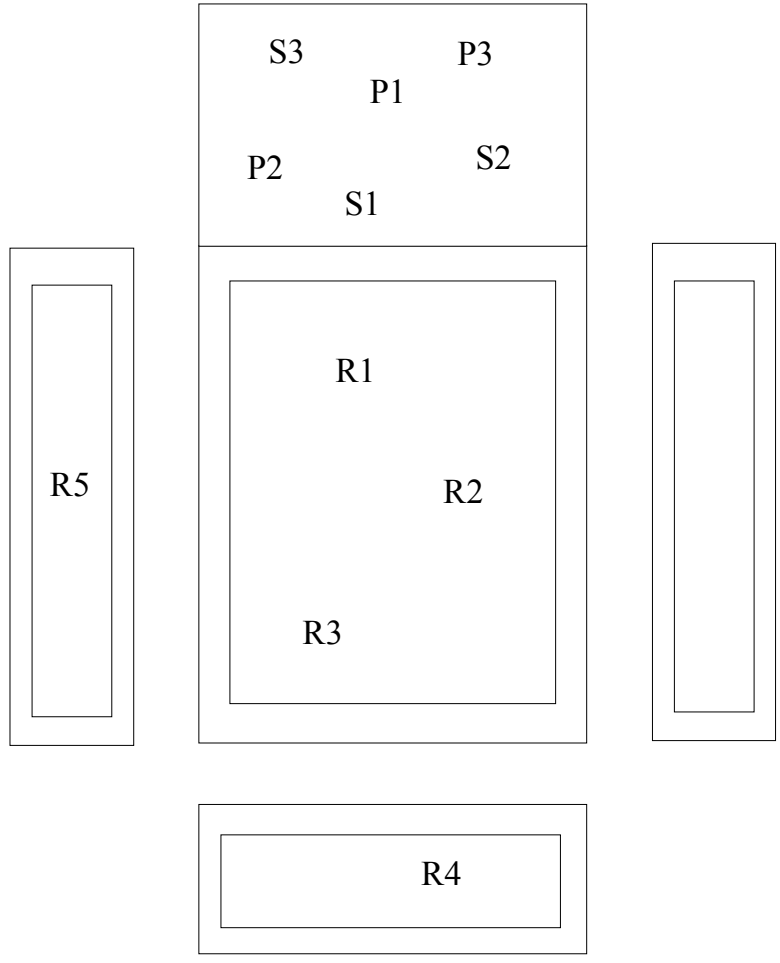
•**S1**: typical soloist position, typically 1 – 1,5 m from the middle.
•**S2**: middle of the right side of strings, in general about 1/3 back from the front and about ¼ in from the side
•**S3**: far left in the second row of the winds, in general 2/3 back from the front and ¼-2/5 in from the side.

Receiver positions on stage

•**P1**: solo oboist, in general about 3/5 from front dead center
•**P2**: middle of left side strings, between first and second violins, in general mirror of S2
•**P3:** far right in second row of the winds, in general a mirror of S3.
•**1 m**:1 m from S positions towards middle of stage

Receiver positions in the audience area

•**R1**: ¼ of the length of the stalls from the front, 2/5 of the width of the stalls from audience left
•**R2**: ½ the length of the stalls from the front, ¼ of the width from audience right
•**R3**: 1/5 of the length of the stalls from the back, 1/3 of the width of the stalls from audience left
•**R4**: on first back balcony, halfway back, 2/5 of the width from audience right
•**R5**: on left side balcony, halfway back and halfway in.



Denotations

f	125	250	500	1000	2000	4000
S1R1	1,1	2,5	20,9	20,9	11,8	4,4
S1R2	22,6	23,8	21,2	22,7	27,5	44,6
S1R3	15,8	8,8	17,6	20	29,2	44,1
S1R4	14,9	19,2	22,5	30,8	40	28,6
S2R1	33,5	28,5	23	35,8	34	34,6
S2R2	11,7	25,3	19	27,1	32,3	33,6
S2R3	9,2	7,4	23,9	21,1	29,4	27,3
S2R4	9,3	16	32,1	31	34,2	28,9
S3R1	10,3	39,4	20,6	21,9	30,6	20,7
S3R2	13	4,7	15,2	27,5	27,2	34,8
S3R3	8,5	21,5	20,3	22,2	26,1	34
S3R4	17,3	18,1	16,7	21	26,7	35
Average	13,93	17,93	21,08	25,17	29,08	30,88
StDev	8,15	10,82	4,33	5,16	6,75	10,67
Min	1,10	2,50	15,20	20,00	11,80	4,40
Max	33,50	39,40	32,10	35,80	40,00	44,60
Var	32,40	36,90	16,90	15,80	28,20	40,20

LF(mid)	23,13	%
LF_4	19,53	%