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Room Acoustics (1)

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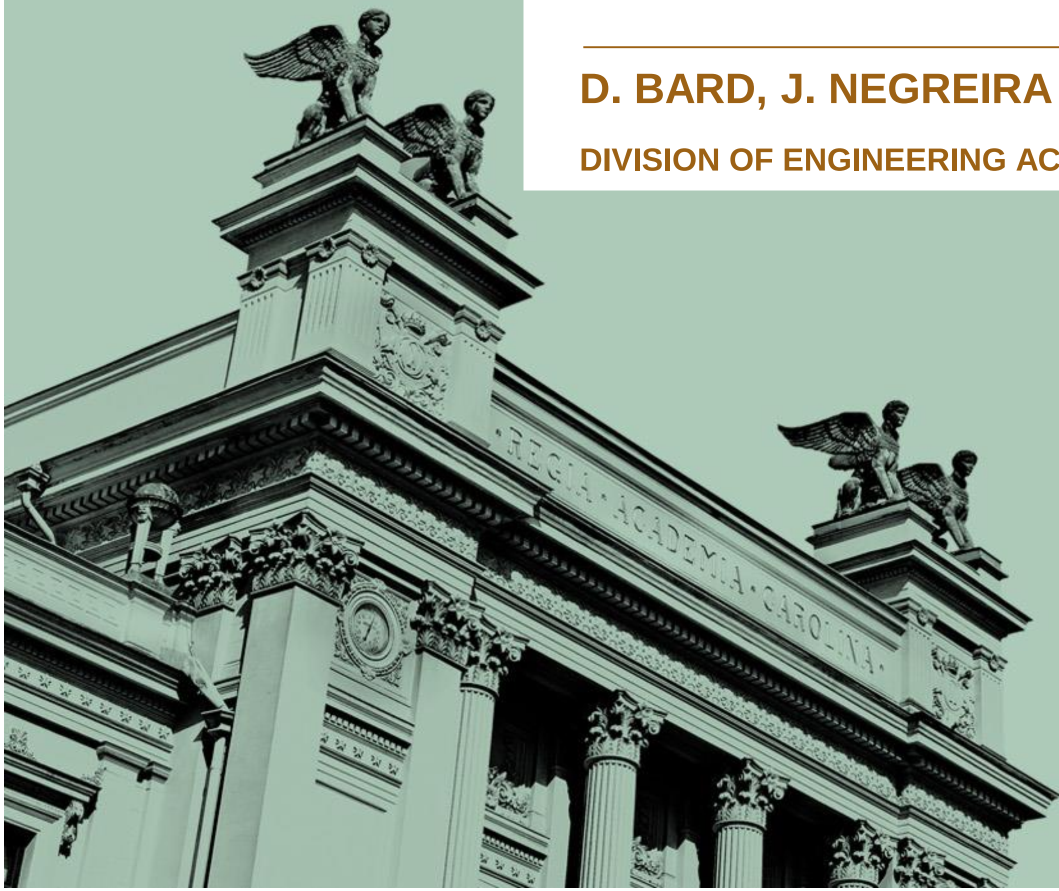

Outline

Room acoustics?

Parameters

Summary

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Basics

- All our life happens (mostly) not in open environments
- We hear not only the source signal but also its reflections
- Multiple propagation paths

What is Room Acoustics?

- All aspects of behaviour of sound in a room
- Good knowledge on the shape of room
  - Dimensions
  - Materials properties
  - Use/ target
  - How many people
  - Etc …

What is Room Acoustics?

- Parameters, measurable and predictable which correlated with subjective impression
- Rt is still a important parameters BUT not only…

Significance of room acoustics

- Room acoustical design
  - Design of sound reflections
  - Design of sound absorption
  - Design of the shape and geometry of the space
- Room acoustical design ≠ maximizing the amount of sound absorbing material
  - E.g. in a lecture hall the performer must be able to speak without restraining ones voice and so that the audience can distinguish what is being said

  Need for both sound absorbing and reflecting surfaces!

- Successful room acoustics is, thus, a combination of the geometry of the space and the absorptive and reflective properties of materials

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Examples of design goals

- Movie theater
  - Hearing the sound track in the way the movie makers have intended it to be heard
- Concert hall
  - Good spatial impression (sound surrounds the listener), sense of intimacy, ”warm” sound color, adequate clarity, etc.
- Restaurant
  - Peaceful acoustical environment (communication from short distance)

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Examples of design goals

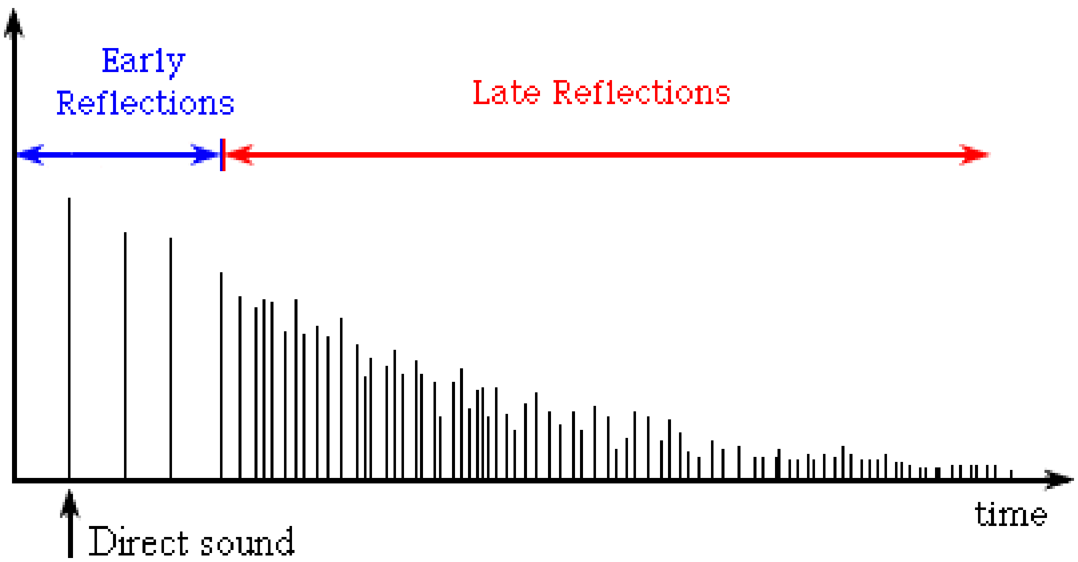
- Open plan office
  - – Speech sound distract concentration , speech privacy between work places
- Factory
  - – Noise level may cause hearing damage , design of effective sound absorption and noise blocking screens

Parameters/ Quality criteria

- **Rt** and/or **sound level reduction** by distance from source may be sufficient in industrial hall
- More parameters must be used in concert hall
- ISO3382 standard
  - All parameters can be measured
  - All parameters are frequency-dependent
  - Based on impulse response measurements

Parameters :Impulse Response Structure

- Pulse is produced at zero time
- Direct arrival (earliest and strongest)
- Early reflections (up to 80 ms, distinct)
- Late reflections
- (high density)
- Late part is a reverberation in a common sense



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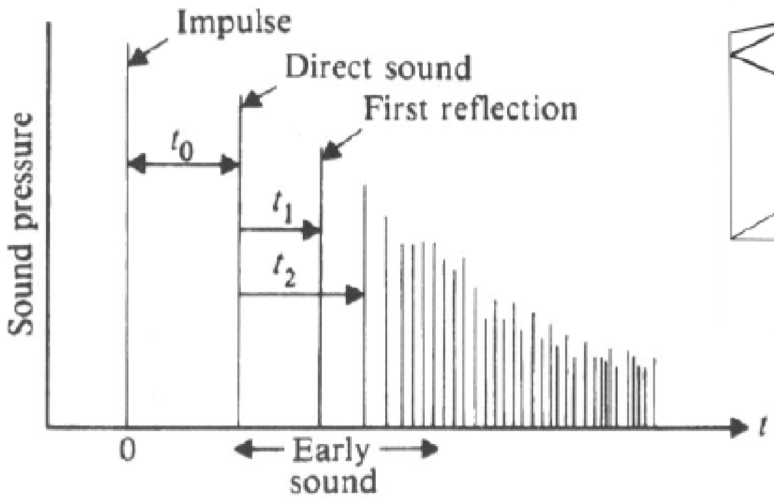
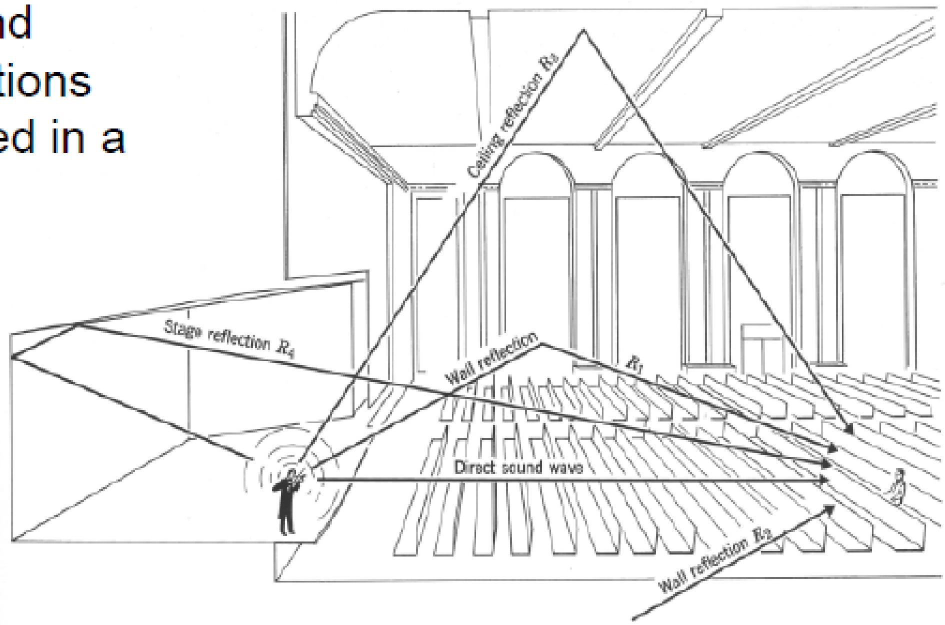
Sound field in a room

Direct sound, early reflections and reverberant sound and their relations determine how sound is perceived in a space





Parameters : Early and Late Reflections

- Early reflections:
  - Strong and distinct
  - Provide spatial information
  - Should be modelled accurately
- Late reverberation:
  - Low intensity and high density of reflections
  - Provide room information
  - No longer depends on source position
  - Can be modelled statistically

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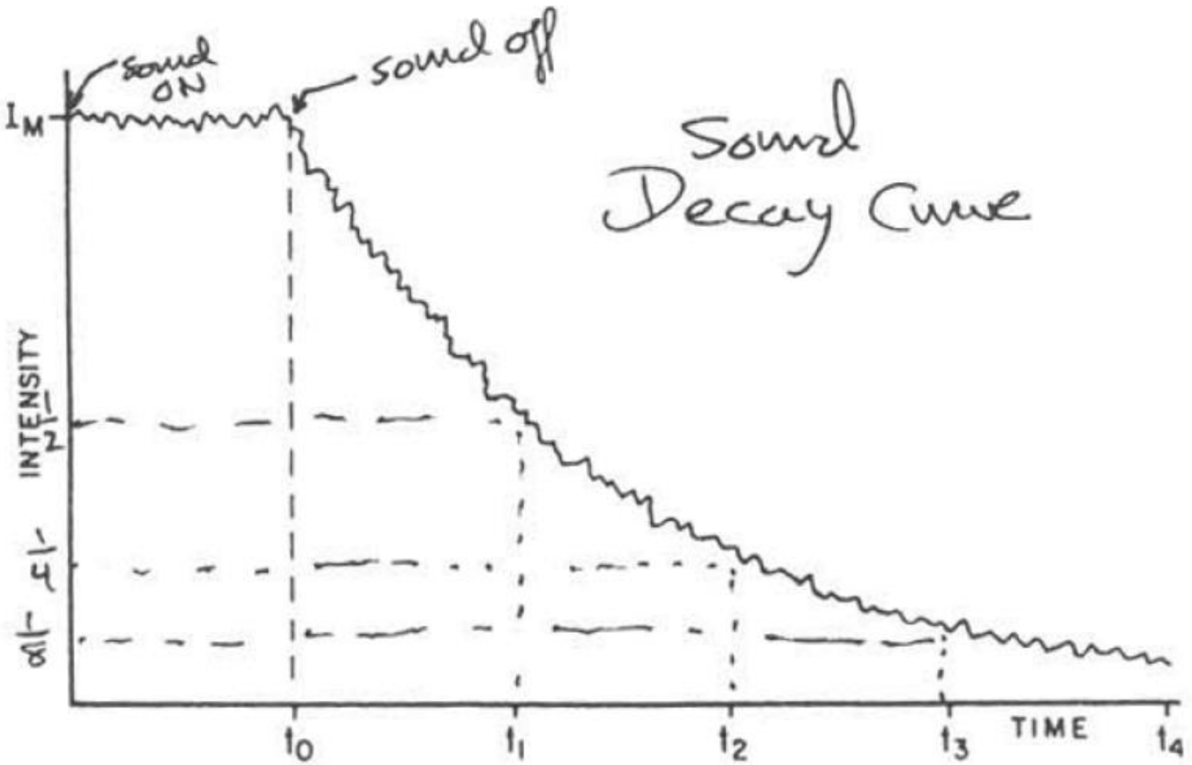
Parameters

- Speech or music design:
  - Give a balanced set in time of the early reflections onto the audience
  - Reflections following the direct within a time spam of approx. **50ms** → Strength of the direct sound
  - But if longer delay: Precedence effect or Hass Effect
- Music:
  - Directional distribution is critical for listener
  - Spaciousness of the sound field
  - Laterals reflections are just as important as reflections form ceiling

Parameters: Reverberation time Rt



Parameters: Reverberation time Rt

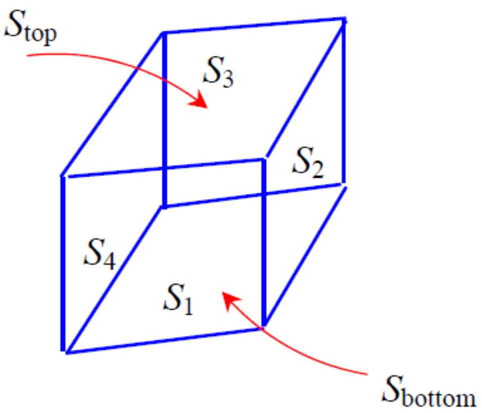
$$\text{Reverberation Time, } T = T_{60} = 0.049\left(\frac{V\left(ft^3\right)}{A\left(ft^2\right)}\right) = 0.161\left(\frac{V\left(m^3\right)}{A\left(m^2\right)}\right) \text{ seconds}$$

= time for sound to decay to 10^{-6} of its original intensity.

If the room has NO holes in it, the area *A* physically represents the effective area of the room that *behaves* as if it were a hole, *due to sound absorption*.

Parameters: Reverberation time Rt

Suppose a room with volume V has a surface area S made up of same material on all 6 sides:



Total surface area of room S:

$$S = \overbrace{S_1 + S_2 + S_3 + S_4}^{\text{area of sides}} + \overbrace{S_{\text{top}} + S_{\text{bottom}}}^{\text{area of top and bottom}}$$

Parameters: Reverberation time Rt

$$A = aS$$

$$a \equiv \frac{A}{S}$$

$a \equiv$ absorption coefficient, $0 \leq a \leq 1$

$a = 0 \;\Rightarrow\;$ **<u>no</u>** sound absorption (no "hole", *i.e.* $A = 0$)
$a = 1 \;\Rightarrow\;$ **<u>total</u>** sound absorption ("hole" = room area, *i.e.* $A = S$!!!)

Parameters: Reverberation time Rt

For a more complicated/realistic room:

$$A = A_1 + A_2 + A_3 + A_4 + \ldots A_N = \sum_{n=1}^{N} A_n$$

$$= a_1 S_1 + a_2 S_2 + a_3 S_3 + a_4 S_4 + \ldots a_N S_N = \sum_{n=1}^{N} a_n S_n$$

for N objects (surfaces) in room.

The "Optimum" Reverberation Time:
* If reverberation time is too short, room sounds "dead"
* If reverberation time is too long, room sounds muddled/obscured

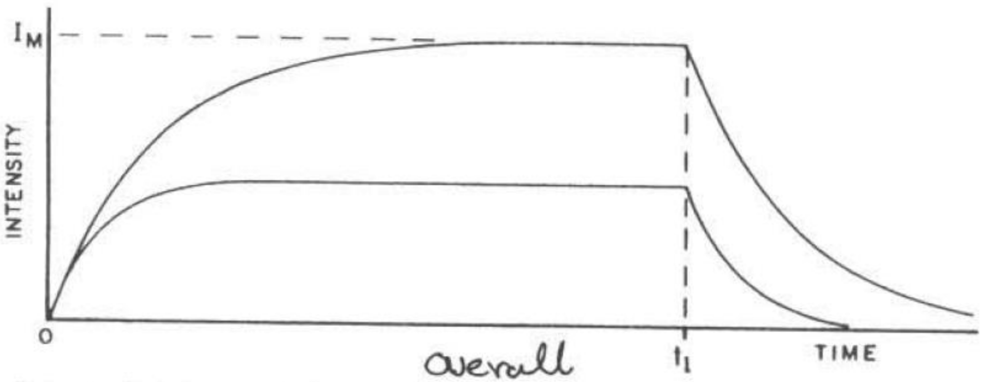


FIG. 4. Buildup and decay of overall sound intensity in an auditorium when a source of steady sound is present.

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Parameters: Optimum Rt

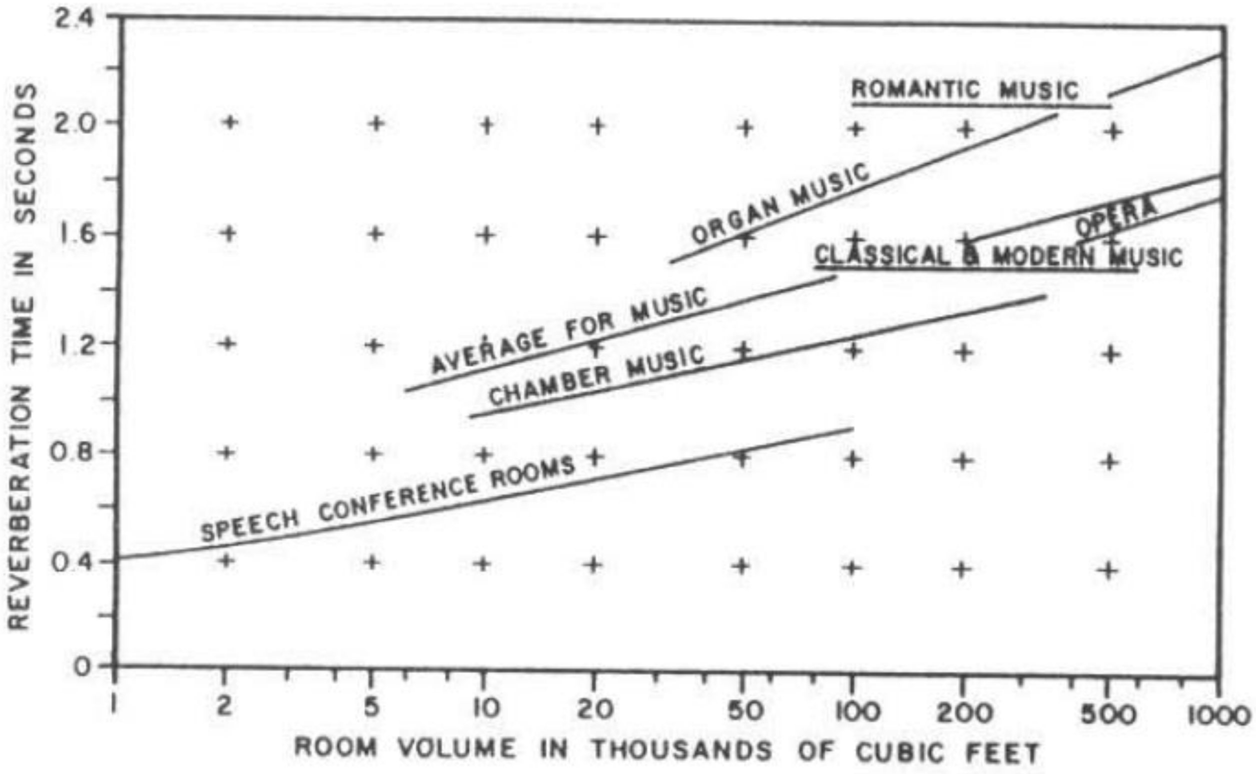

FIG. 5. Optimum reverberation time for auditoriums of various sizes and functions at a frequency of 500 hertz.

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Parameters: Reverberation time Rt

- EDT : early decay time
- From the first 10dB of decay

Parameters: Speech intelligibility

$$\boxed{D_{50} \equiv 100 \times \left[\frac{\int_{t=0}^{t=50ms} p^2(t)dt}{\int_{t=0}^{t=\infty} p^2(t)dt} \right] \quad (\%)}$$

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Parameters: Clarity

- Balance between early and late arriving sound energy.

A related statistic is ***speech*** Clarity, C_{50} defined as:

$$\boxed{C_{50} \equiv 10\log_{10}\left(\frac{\int_{t=0}^{t=50ms} p^2(t)dt}{\int_{t=0}^{t=\infty} p^2(t)dt - \int_{t=0}^{t=50ms} p^2(t)dt}\right) \quad (dB)}$$

For > 80% syllable intelligibility, a clarity of $C_{50} > -2dB$ is required, and is considered the minimum admissible limit for good speech intelligibility.

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Parameters: Clarity music

Music Clarity, C_{80} defined as:

$$\boxed{C_{80} \equiv 10\log_{10}\left(\frac{\int_{t=0}^{t=80ms} p^2(t)dt}{\int_{t=0}^{t=\infty} p^2(t)dt - \int_{t=0}^{t=80ms} p^2(t)dt}\right) \quad (dB)}$$

Parameters: Center Time

Another statistic is the Center Time $\langle t_s \rangle$, the mean/average time associated with a sound impulse, defined as:

$$\langle t_s \rangle \equiv \left[\frac{\int_{t=0}^{t=\infty} t \cdot p^2(t)dt}{\int_{t=0}^{t=\infty} p^2(t)dt} \right]$$

Parameters: Syllable intelligibility

The {subjective} mean/average syllable intelligibility $\langle V_s \rangle$ is related to the center time $\langle t_s \rangle$ by:

$$\boxed{\langle V_s \rangle \equiv 96 \cdot \left(1 - 10^{-5} \langle t_s \rangle^2\right) \quad (\%)} \quad n.b.\ \langle t_s \rangle \text{ in } msec \text{ time units, here.}$$

For mean/average syllable intelligibility $\langle V_s \rangle > 80\%$, a center time of $\langle t_s \rangle \leq 130\ msec$ is required.
If the center time is measured *vs*. octave bands center frequencies, then for speech one wants $\langle t_s (f_{ctr}) \rangle \leq 60 - 80\ msec$ for the 4 octave band centers at 500 *Hz*, 1000 *Hz*, 2000 *Hz* & 4000 *Hz*.

Parameters: Relation

- The relationship between *C*50 and *D*50 is then given by

$$C_{50} = 10 \cdot \lg\left(\frac{D_{50}}{1 - C_{50}}\right),$$

Parameters: Lateral energy fraction LF

- 8 microphone has to be used

$$LF = \int_{5\mathrm{ms}}^{80\mathrm{ms}} p_{\mathrm{L}}^{2}(t)\,\mathrm{d}t \bigg/ \int_{0}^{80\mathrm{ms}} p^{2}(t)\,\mathrm{d}t,$$

- LFC, contribution will be function of cosine to this angle, more subjectively accurate

$$LFC = \int_{5\mathrm{ms}}^{80\mathrm{ms}} \left|p_{\mathrm{L}}(t)\cdot p(t)\right|\mathrm{d}t \bigg/ \int_{0}^{80\mathrm{ms}} p^{2}(t)\,\mathrm{d}t.$$

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Parameters: Importance

- T30, EDT: Reverberation
  - T60 = 2*T30
- D50: Clarity of speech
- C80: Clarity of music
- LF, LFC: Spatial impression
- Desired parameters depend on the purpose
  - Optimal T60 for speech: 40-60 ms
  - Optimal T60 for music: > 100 ms

Parameters: Critical Distance

- As you go further from source, direct sound level drops
- In contrast, reverberant sound level stays constant everywhere in the room
- Distance at which they are equal is the critical distance Dc

$$D_c = \left[\frac{S_e}{16\pi} \right]^{1/2}$$

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Parameters: Summary

Parameter	Definition	JND
T_{30}, s	Reverberation time (energy drop from –5 to –35 dB)	5%
EDT, s	Early decay time (energy drop from 0 to –10 dB)	5%
D_{50}, %	Deutlichkeit (definition), ratio of early (0-50ms) to total energy	5%
C_{80}, dB	Clarity, ratio of early (0-80ms) to late (80ms-…) energy	1 dB
TS, ms	Center time, time of the 1st moment of IR	10 ms
G, dB	Sound level at 10m from the omnidirectional source, referenced to free-field level (as if no room at all)	1 dB
LF, %	Ratio of early (5-80ms) energy weighted by $\cos^2$(lateral angle) (i.e., lateral energy) to total energy	5%
LFC, %	Ratio of early (5-80ms) energy weighted by cos(lateral angle) (i.e., lateral energy) to total energy	5%
IACC	Interaural Cross Correlation Coefficient	0.2

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Wavelength Influence

- Wavelength << object size:
  - Specular reflection (walls)
- Wavelength >> object size:
  - No effect (coffee mug)
- Wavelength ~ object size:
  - Diffraction (table) (most complicated)

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Thank you for your attention!

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