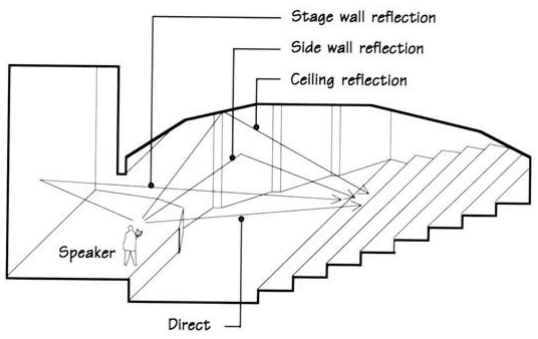
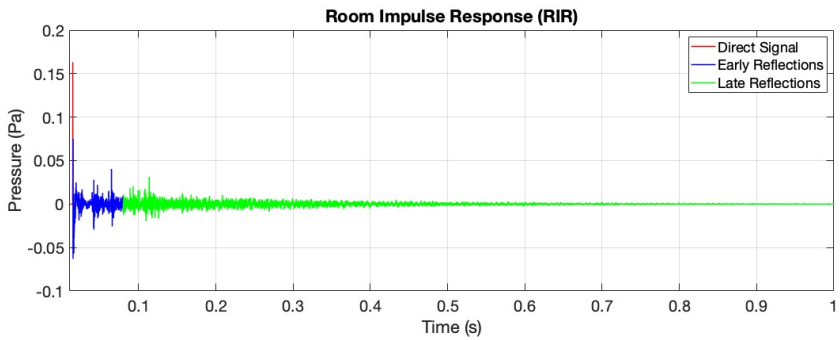
Hand-in Assignment #2: Room Acoustics

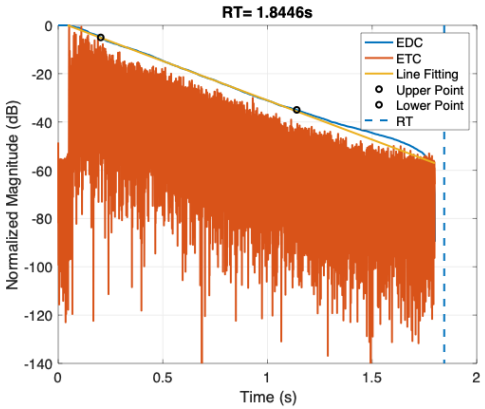
7LS8M0: Architectural Acoustics

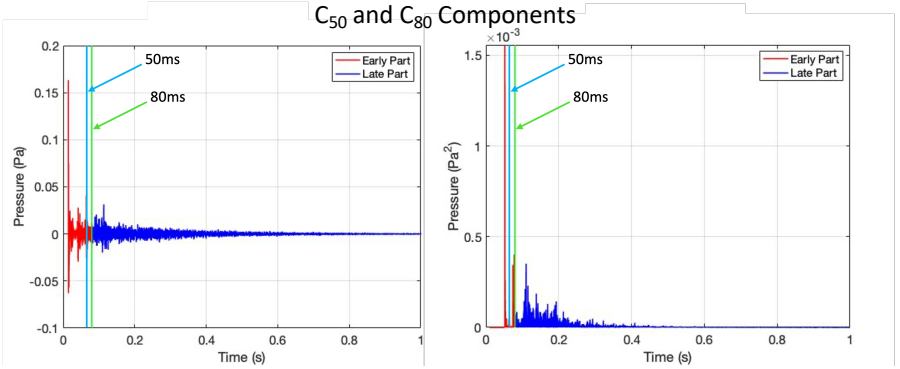
M.E. (Michalis) Terzakis

Building Acoustic Group









Department of the Built Environment

16-Mar 2022

Assignments Instructions

- Report
  - No-need of including theoretical background or repeating the questions writen in the guideline.
  - Include the plots in a high quality.
  - Answer the questions in a motivated way.
- Report structure (proposal)
  - Introduction (in-short): What is the purpose of the assignment.
  - Tasks: with a short description + answers.
  - Conclusion (in-short): Summary of the main reamarks with respect to the purpose of the assignment.
  - References.
  - Appendix: MATLAB codes, including comments.

Evaluation Criteria

Introduction to Tutorials

Assignments Evaluation Criteria

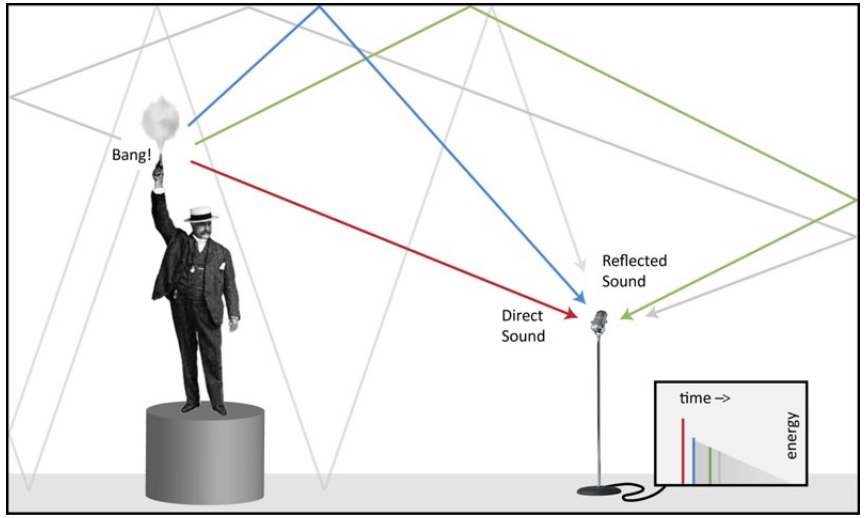
- MATLAB-based Assignments
  - Clear structure and language in the report.
  - High quality of references and correct citation.
  - Correct approach and results.
  - Clear and well illustrated figures, including all the information (i.e., title, axes labels, and legends).
  - Correct implementation in MATLAB.
  - Inclusion of explanation comments in MATLAB.
  - Correct intepretation of the results supported by literature.
- Concept Presentation Assignment
  - To be announced later.

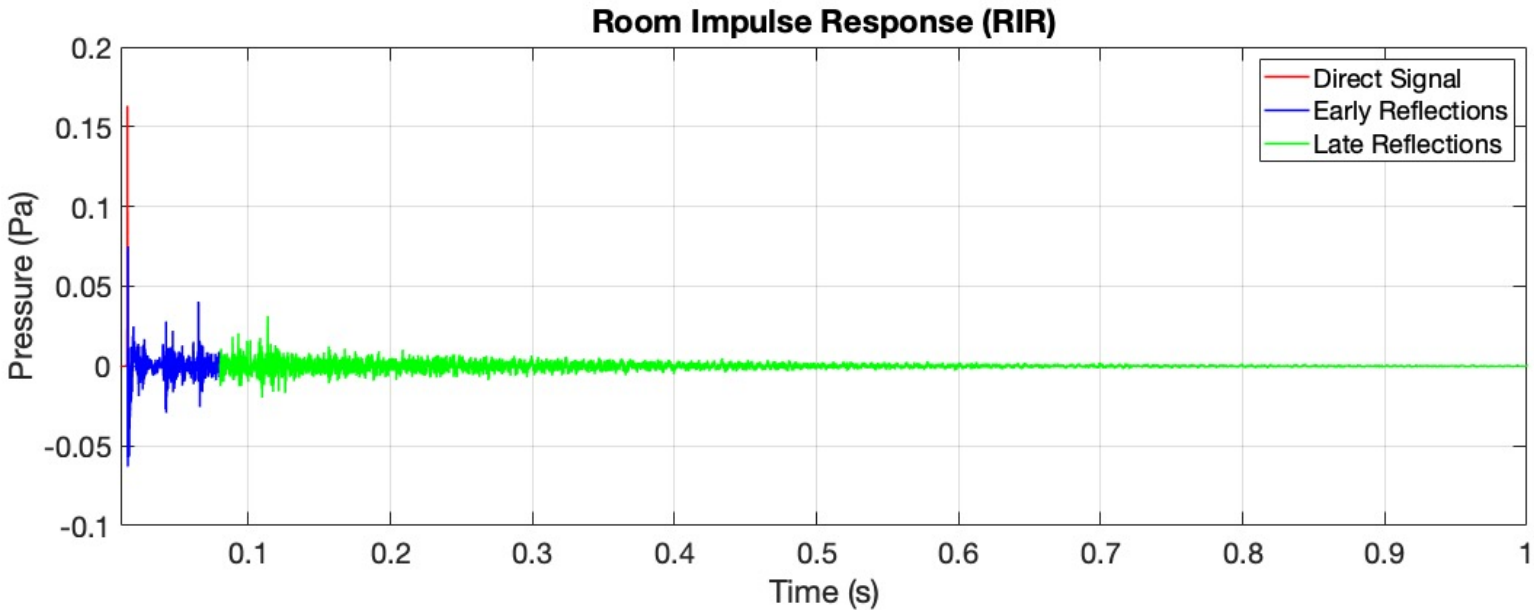
Tasks of the Assignment HA2

- Exploring the Room Impulse Responses (RIRs)
  - Filtering the Room Impulse Responses
  - Energy Time Curve (ETC)
- Analyzing the Room Impulse Responses (RIRs)
  - Energy Decay Curve (EDC)
  - Estimation of the Reverberation Time (T_{30})
  - Clarity (C_{50} and C_{80})
  - Centre-Time (T_s)
- Case Study

Exploring the Room Impulse Response(s)

Room Impulse Response (RIR)



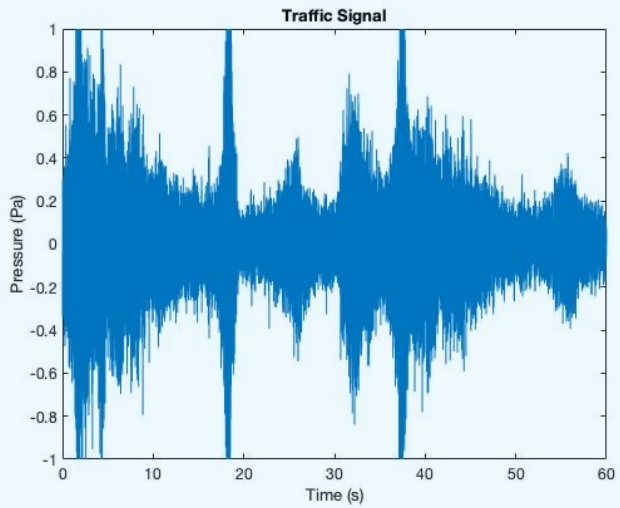


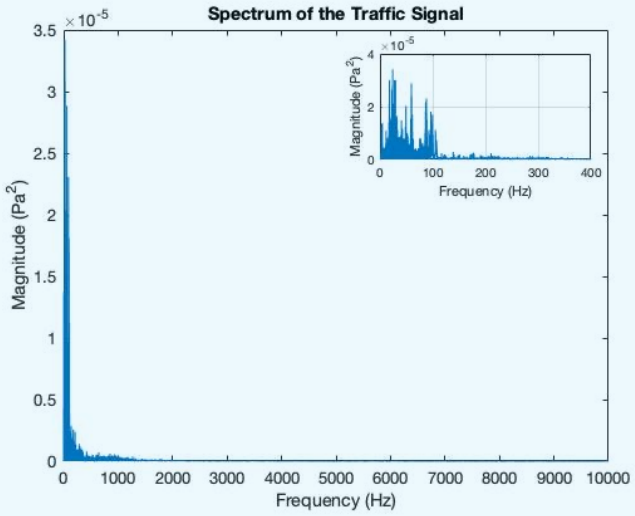
<u>Question:</u> How could we calculate the distance between sound source (SRC) and receiver (REC)?

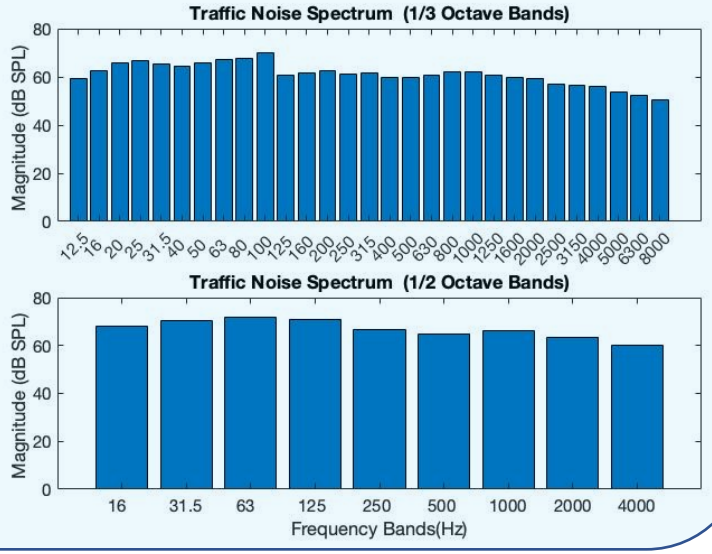
Direct Sound: $x = c \cdot t_{direct}$, assuming $c = 343m/s$

Filtering of the Room Impulse Response (in Time-Domain)

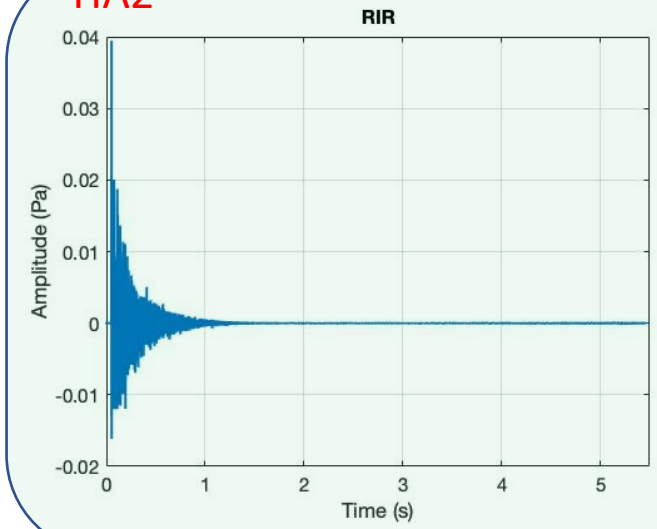
HA1

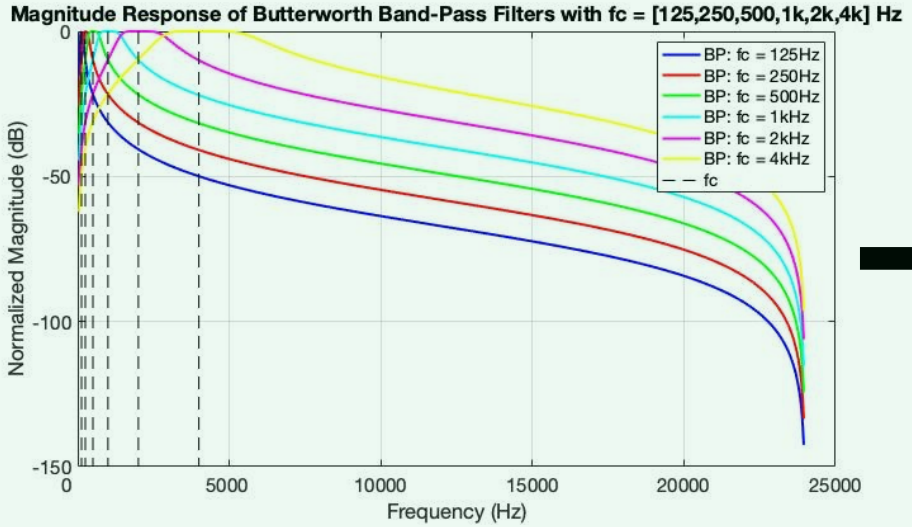


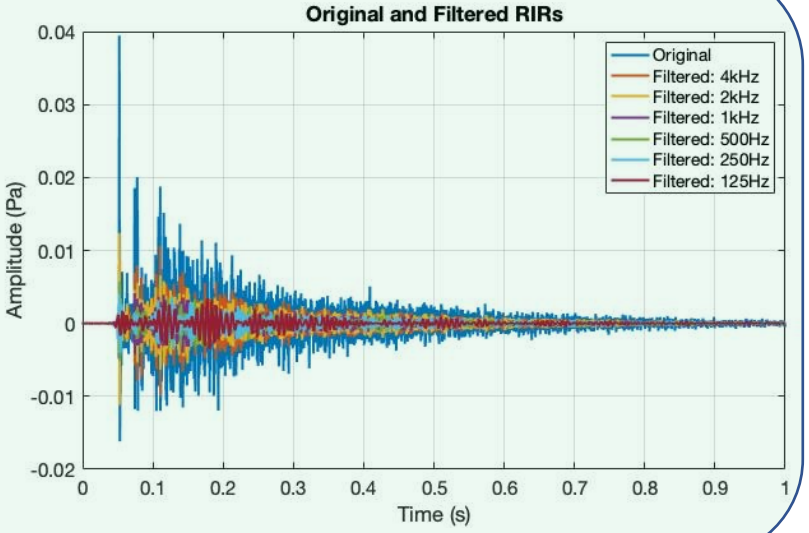




HA2







Filtering of the Room Impulse Response (in Time-Domain) [Code]

```
%% ------------------------ Start of Filtering code ------------------------
% 1/1-Octave frequency bands definitions
fc = [125 500]; % Center frequencies
f_l = 2.^(-1/2).*fc; % Lower limit
f_h = 2.^(1/2).*fc;  % Upper limit

order = 3; % 2nd order Butterworth filter

fnq = fs/2; % Nyquist frequency

% You have to repeat the next steps in a for-loop to do the filtering for
% each 1/1-octave frequency band.

for n=1:length(fc)

    % Butterworth bandpass non-dimensional frequency
    Wn = [f_l(n)/fnq f_h(n)/fnq];

    % Filters construction
    [b,a] = butter(order,Wn,'bandpass');

    % Filtering of the time signals.
    FiltRIR1(n,:) = filtfilt(b,a,RIR1);
    % ======================================================================
    % Explanation:
    % ======================================================================
    % Time-signal filtered for the 125Hz and 500Hz 1/1-octave centre
    % frequency bands. The FiltRIR1 is basically the variable ho(t) in the
    % Expression (1) at the page 3 in the HA2 guideline). FiltRIR1 is a
    % MATRIX (not a vector), where the filterd-time signal for the octave
    % band 125Hz is stored on the first row of the matrix and the 500Hz on
    % the second row. Note: Check the matrix for better understanding
    % (double click on FiltRIR1 on the Workspace window).
    % ======================================================================
end

% ------------------------ End of Filtering code -------------------------
```

Filtering in 1/1-octave frequency bands

Definition of the order of the filters.

For each defined 1/1-octave frequency band

Bandwidth(s) of the filter(s)

Design of Butterworth band-pass filter(s) of 2nd order

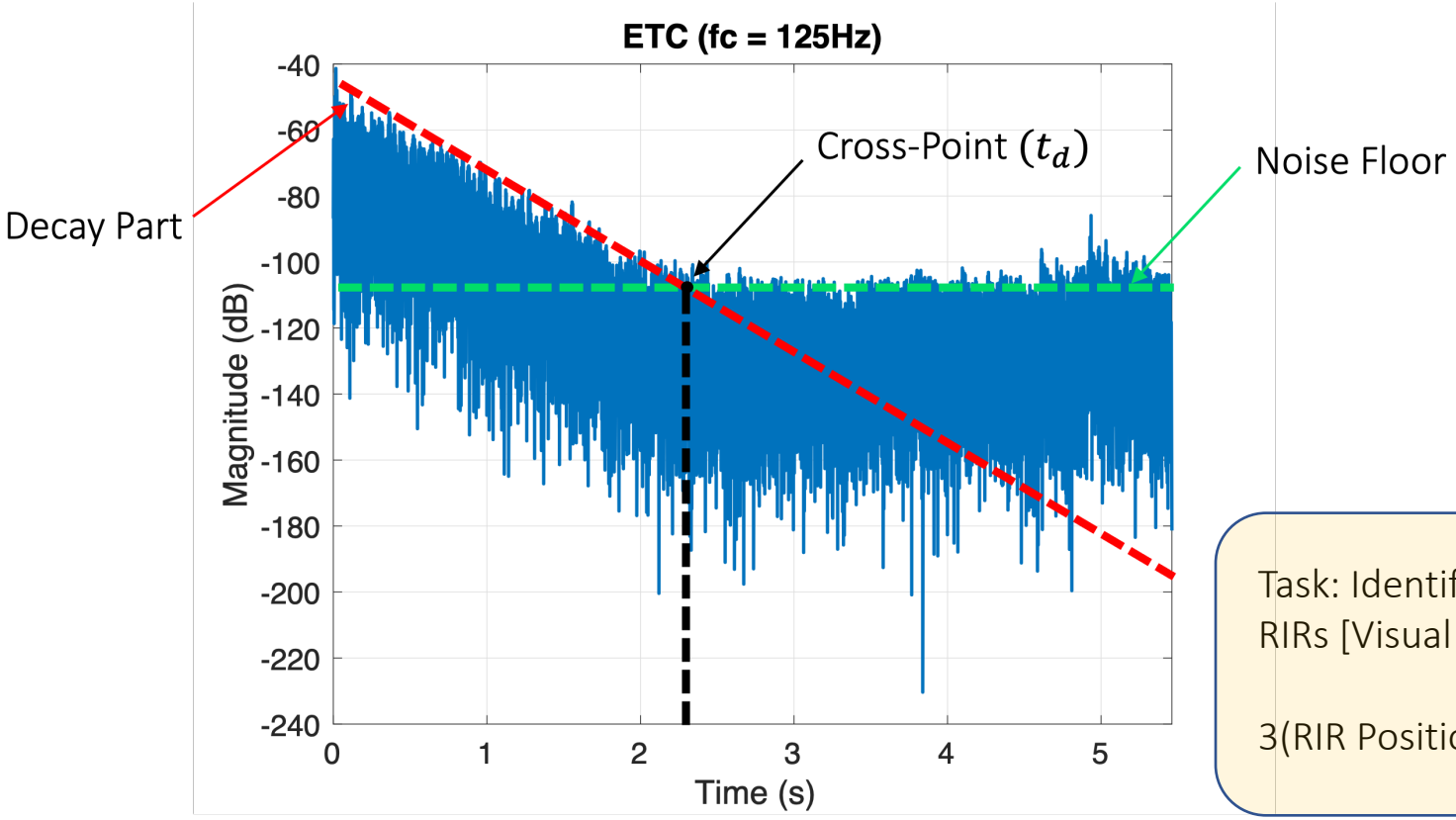
Filtered Room Impulse Response

Matrix: Storing each filtered Room Impulse Response in each row

Energy Time Curve (ETC)

- Definition:

$$ETC_o(t) = 10\log_{10}\left(h_o^2(t)\right) \quad [dB] \quad (1)$$



Task: Identify of t_d in each ETC for all the RIRs [Visual way]

3(RIR Positions) x 6(ETC per f_c) = 18 (t_d)

Analysing the (Filtered) Room Impulse Response(s)

Energy Decay Curve (EDC)

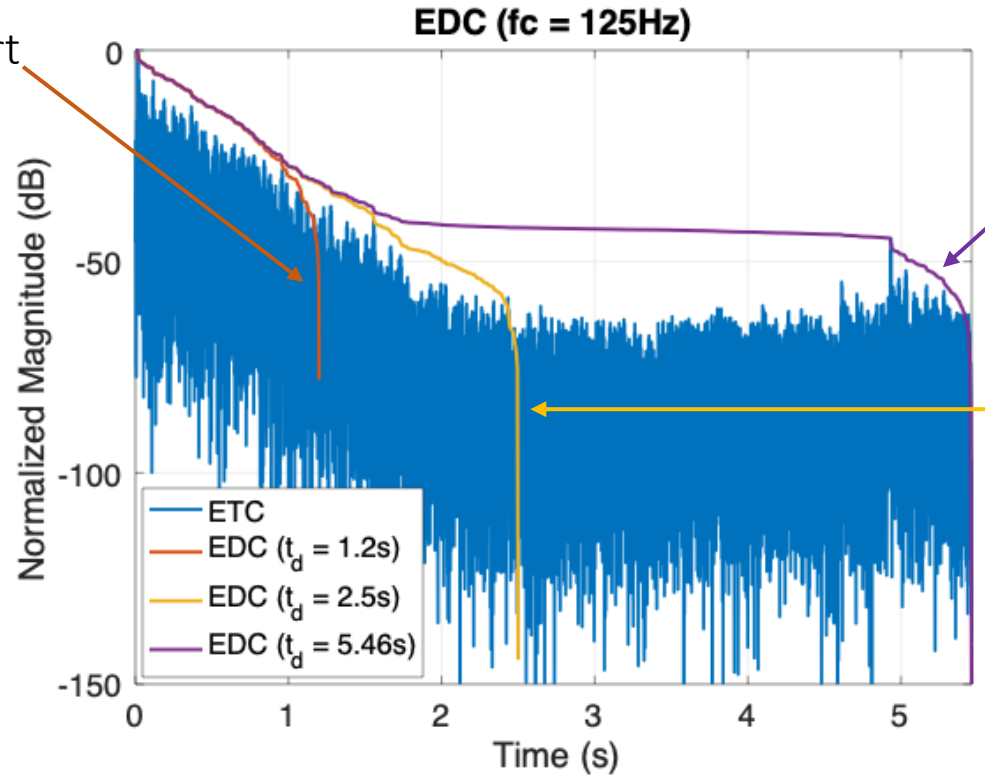
- Definition:

$$EDC_o(t) = 10\log_{10}\left(\frac{\int_{t_d}^{\infty} h_o^2(\tau)d\tau}{\int_0^{\infty} h_o^2(\tau)d\tau}\right) = 10\log_{10}\left(1 - \frac{\int_0^{t_d} h_o^2(\tau)d\tau}{\boxed{\int_0^{\infty} h_o^2(\tau)d\tau}}\right) \quad [dB] \quad (2)$$

- In discrete domain the integral is sum.
- Limits related to the samples.
- Infinity in discrete domain is the duration in Samples
- MATLAB indices start from 1.

$\mathrm{sum}(\mathrm{RIR1_o}(1{:}\,\mathrm{durationSamples}).\,\hat{}\,2)$ where, $\mathrm{durationSamples} = \mathrm{round}(\mathrm{t_d} \cdot \mathrm{f_s}, 1)$

Overestimation of Early Part



Underestimation of Early Part

Correct estimation of Early Part

Estimation of the Reverberation Time (T_{30})

- **Reverberation Time:** The time that passes after an acoustic source in a room has been turned off until the sound pressure by $60dB$.
- **Limitation:** Achieve a decrease of $60dB$ in the dynamic range.
- **Solution:** Measuring in a range from $-5dB$ to $-35dB$ and then implying the linearity assumption $T_{30} = 2 \cdot \{t_{-5dB} - t_{-35dB}\}$.
- **Estimation Method:** Fitting a first order polynomial (i.e., $y = a \cdot t + b,\ a, b \in \mathbb{R}$) in the range from $-5dB$ to $-35dB$, and extrapolating the linearity to $-60dB$, where the reverberation time is estimated ($T_{30} = -60dB/a$).

```
% ==========================================================================
% Polyfit Function Notes:
% ==========================================================================
% Input argument 1: Values of the time-vector, corresponding to the posi-
%                   tions from L1 level until L2 level in EDC.
% Input argument 2: Values of the EDC, corresponding to the positions from
%                   L1 level until L2 level in EDC.
% Input argument 3: Order of the fitted polynomial.
% Ouput Argument 1: Coefficients of the fitted polynomial.
% ==========================================================================
```

```
function [T30] = RTLinFit(EDC,fs,RIRNum,octBand,plt)
%% [RevTime] = RTLinFit(EDC,fs,RIRNum,octBand,plt)
% This function estimates the reverberation time using a linear fitting
% extrapolation based on an interpolation in the range under consideration.
% Also, it returns a figure including the interpolated ponts, the EDC, as
% well as the Reverberation time (T30). Note: The RIRNum and octBand
% arguments are used in ploting.
```

...

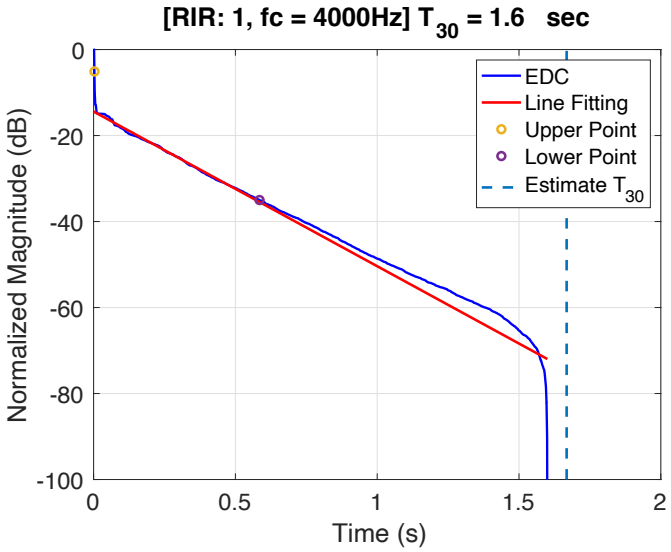
```
% Definition of the upper and lower levels in dBs.
L1 = -5;
L2 = -35;

% Compute the time vector of the EDC.
timeVector = ... ;

% Find the position (index) of the EDC level which is close to L1 level.
idxL1 = ... ;

% Find the position (index) of the EDC level which is close to L2 level.
idxL2 = ... ;
```

...

```
% Fit a first order polynomial [y = at + b], using the polyfit function.
% This function returns the coefficients a and b. Check: help polyfit
```

...

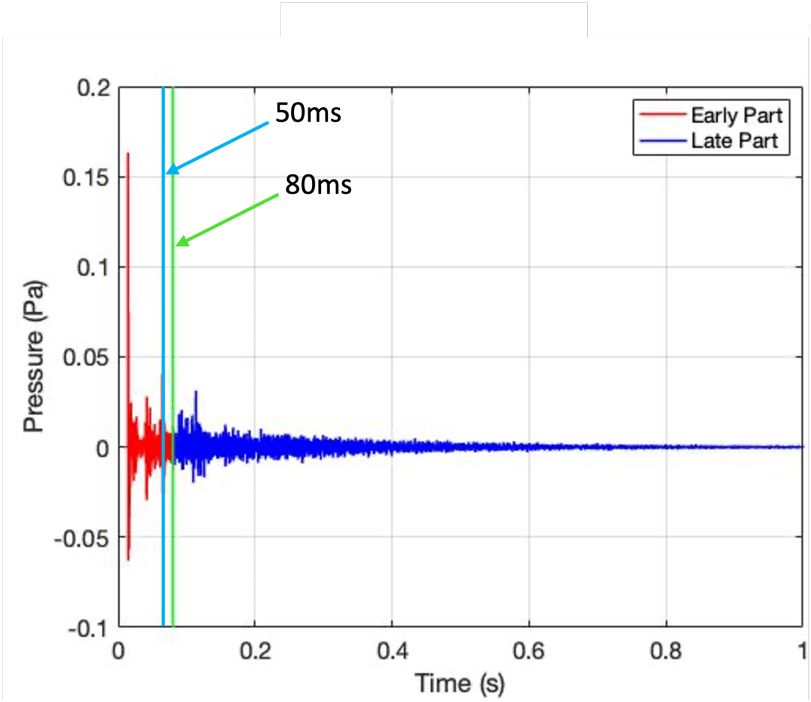
```
% Estimation of the coefficients (i.e., a & b) of a first order polynomial.
[Coefs,~] = ... ;

% Extrapolate fitting line to -60dB, estimating T30 (i.e., Expression (3)).
RevTime = ... ;
```

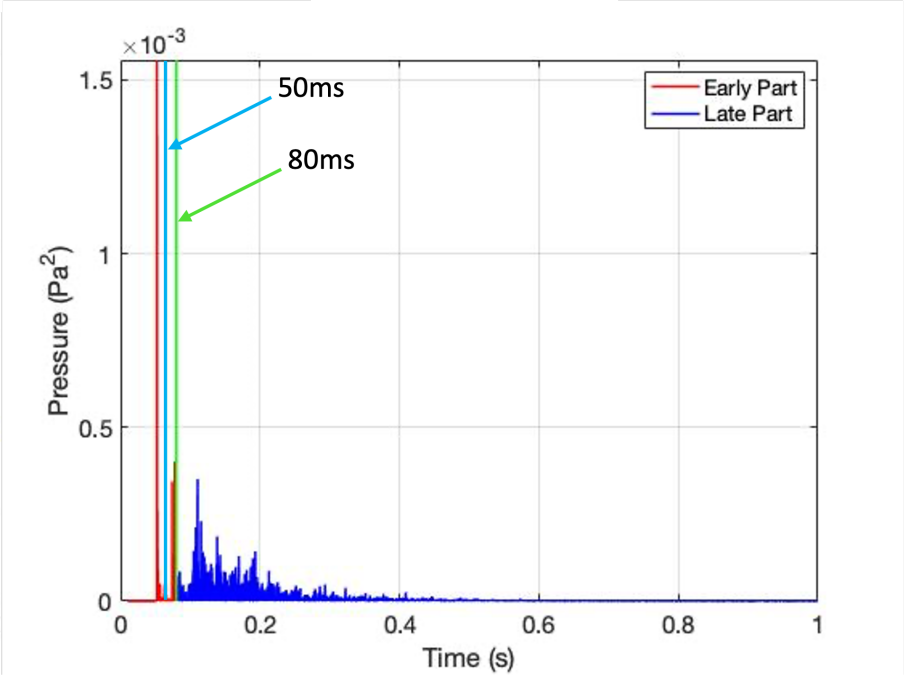


Clarity (Speech: C_{50} and Music: C_{80})

- **Usage:** Quality of speech (C_{50}) and music (C_{80}) in enclosed space.
- **Physical Meaning:** Energy ratio between early (i.e., C_{50}: $[0, 50ms]$, C_{80}: $[0, 80ms]$) and late reflections (i.e., C_{50}: $[50ms, \infty]$, C_{80}: $[80ms, \infty]$)
- **Mathematical Definition:**

$$C_{50,o} = 10\log_{10}\left(\frac{\int_0^{50ms} h_o^2(t)dt}{\int_{50ms}^{\infty} h_o^2(t)dt}\right) \quad \text{and} \quad C_{80,o} = 10\log_{10}\left(\frac{\int_0^{80ms} h_o^2(t)dt}{\int_{80ms}^{\infty} h_o^2(t)dt}\right) \quad [dB] \quad (3)$$





Centre-Time (T_s)

- **Usage:** "Spatial" acoustics impression.
- **Physical Meaning:** Domination of the direct field over the reverberant field (i.e., small values) and vice versa (i.e., high values).
- **Mathematical Definition:**

$$T_{s,o} = \frac{\int_0^\infty t \cdot h_o^2(t)dt}{\int_0^\infty h_o^2(t)dt} \cdot 1000 \quad [msec] \quad (4)$$

Case-Study

- Investigation of the usage of the enclosed space based on the results and the proposed literature.

Music and/or Speech?

- Assume that the three RIRs characterize the whole enclosed space.

Would you suggest a acoustic modification?

- Listening to the RIRs which were convolved with a speech signal and an flamenco guitar,

Do your listening experience matchs with their results?

Final Remarks

- Read (very) very carefully the *guideline*.
- Read very carefully the *examples*.
- For questions [e-mail and/or StudyHub Hours on Fridays].
- HA2 deadline: 30-03-2022 @ 23:59.