Biomedical Sensors and Signal Processing

Master of Data Science for Health – Course 2022/2023

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Estimation of the respiratory system impedance using multisinusoid signals

Introduction: Biomedical background

Chronic obstructive pulmonary disease (COPD) is a chronic lung disease that causes inflammation of the airway tissue, tissue damage, and extra breathing effort on the part of the patient. It is characterized by a narrowing (obstruction) of the airways and an increase in tissue stiffness. The symptoms of COPD are difficulty breathing and a chronic cough with or without sputum. In the long run, it produces chronic fatigue and weight loss. A feature of the disease is that there are recurrent periods of worsening symptoms known as exacerbations. They are produced by infection or air pollution. Exacerbations accelerate the deterioration in the patient's health.

The main **causes** of COPD are:

- **Tobacco smoke**: About 50% of lifelong smokers develop COPD, compared to 10% in the general population.
- **Occupational exposure:** About 20% of COPD cases are related to exposure to air pollution, sometimes related to working conditions (dust, volatile organic compounds, etc.).

Lung infections and exposure to fire fumes in childhood are environmental risk factors. It is known that certain genetic conditions make people more susceptible to develop COPD.

While there is no cure for COPD, a proper disease management can improve the patient quality of life. The **therapy** associated to COPD is:

- Quitting smoking, and reduce exposure to air pollution
- Physical exercise to improve overall health condition
- Medical treatment with bronchodilators to improve lung ventilation and facilitate respiration
- Oxygen therapy

The diagnosis of COPD is typically carried out through spirometry. The spirometer measures the flow vs time and produces some characteristic Flow-Volume plots called spirograms.

To have a correct spirometry test, the subject must inhale as much air as possible filling the lungs to their maximum capacity, and then exhale at the maximum flow till flow goes to zero. This requires the collaboration of the patient, and for people in severe COPD condition produces coughs, and often nauseas. Incorrect manoeuvres lead to inconsistent results that can lead also to misinterpretation of the condition of the subject. Spirometry is not a valid technique for babies and toddlers. Often elderly people, or subjects with mental health issues, do also have difficulties to carry out a proper spirometry.

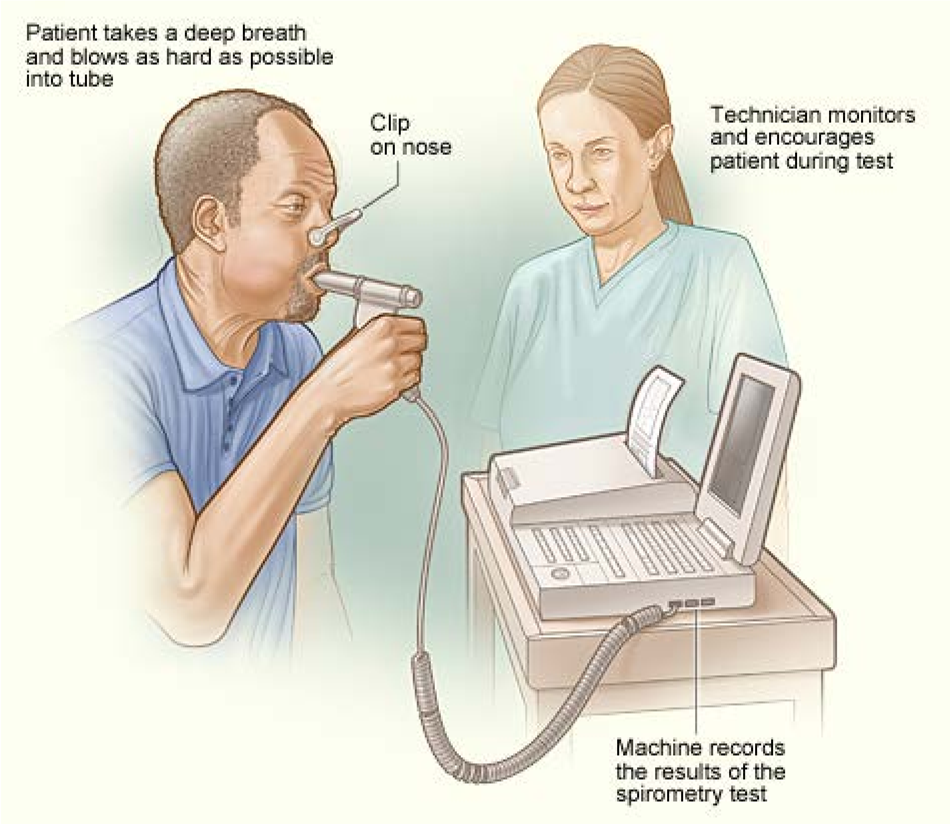

Figure 1 Spirometry test (from Wikipedia)

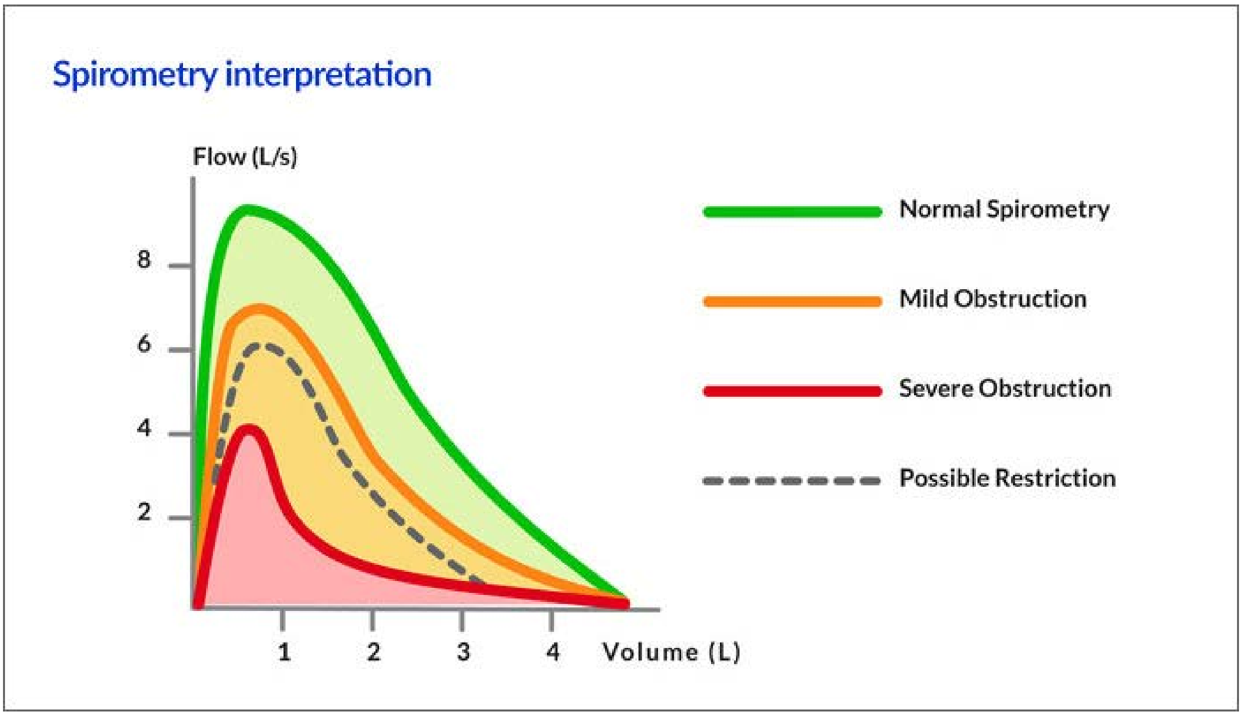

Figure 2 Spirograms and their interpretation (from Wikipedia)

The Forced Oscillation Technique (FOT)

An alternative to study the mechanics of the respiratory system is the Forced Oscillation Technique and related variants. The main idea is that the respiratory system can be modelled as a linear and time invariant system, where the input is pressure, and the output is flow. In this sense, the respiratory system is often modelled as an equivalent electrical circuit where current takes the role of flow and voltage the role of pressure. FOT aims to measure the complex impedance in the frequency range 5-30 Hz. Take into account that the complex impedance is the inverse of the frequency response. The FOT was developed initially by DuBois and coworkers in 1956.

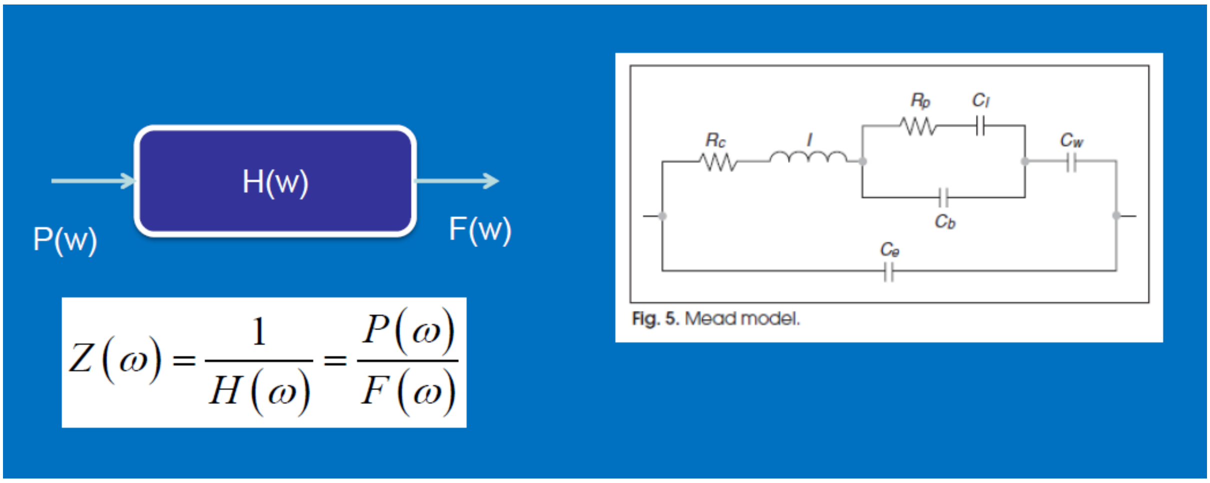

Figure 3 The respiratory system is modelled as a LTI system, with pressure as input and flow as output.

In this technique, while the patient is breathing normally a loudspeaker applies a pressure signal in the mouth of the patient and a flow sensor measures flow in response to the pressure excitation. Here you can see an actual image of the system. The measurement take about 20s normally. Patient normal breath can be eliminated by high pass filtering because it appears at lower frequencies (typically below 1 Hz). In some cases, the patient simulates an apnea for few seconds to prevent the FOT signals to be polluted by the breath signal. Cheek support is recommended to cancel out the dynamics of the mouth cavity.

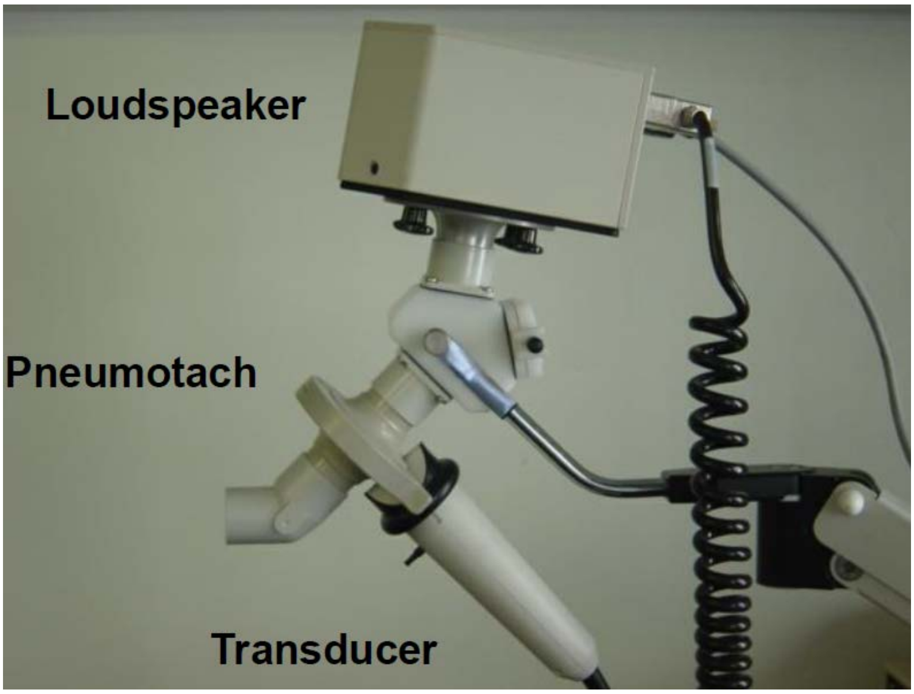

Figure 4 Image of a FOT system

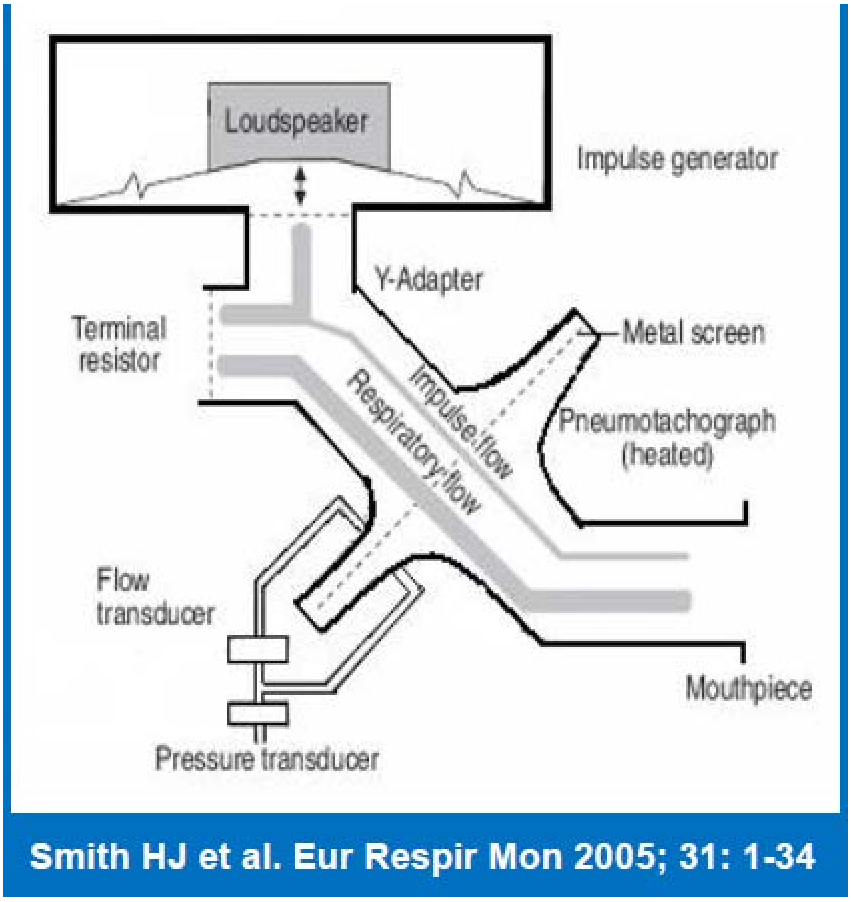

Figure 5 Schemactic representation of the FOT system. The measurement of the flow is based on the differential pressure drop caused by a metal screen.

The characterization of the frequency response of the respiratory system can be based in different excitation signals.

- **Single frequency sinusoids** sweeping the frequency range of interest.
- A **linear combination of sinusoids** that cover the frequency range of interest. A Fourier series analysis of the output allows to separate the response to the different excitation frequencies.
- **Pressure impulses** to obtain the system impulse response, followed by Fourier Transform
- **Random Noise.**

In this lab we are going to explore signals obtained by a linear combination of three sinusoids.

The final diagnostic can be based on the inspection of the real and imaginary part of the complex impedance. The real part (or resistive component) informs about the airways obstruction, while the imaginary part that shows a resonance behaviour (crosses the zero at a certain frequency), informs about the stiffness of the respiratory system. An increased stiffness produces an increase of the resonance frequency.

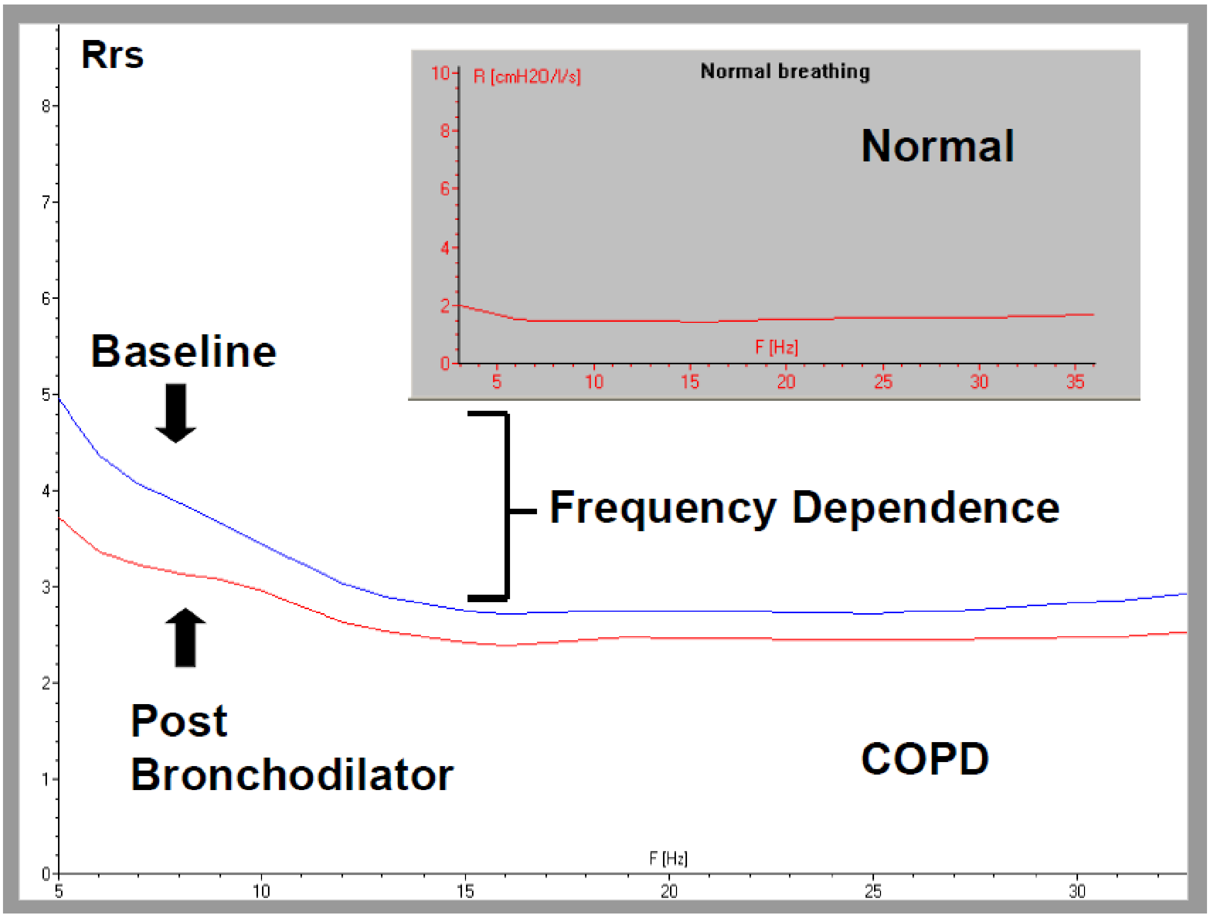

Figure 6 COPD patients have an increased resistance, specially at low frequencies. Application of a bronchodilator reduces the obstruction.

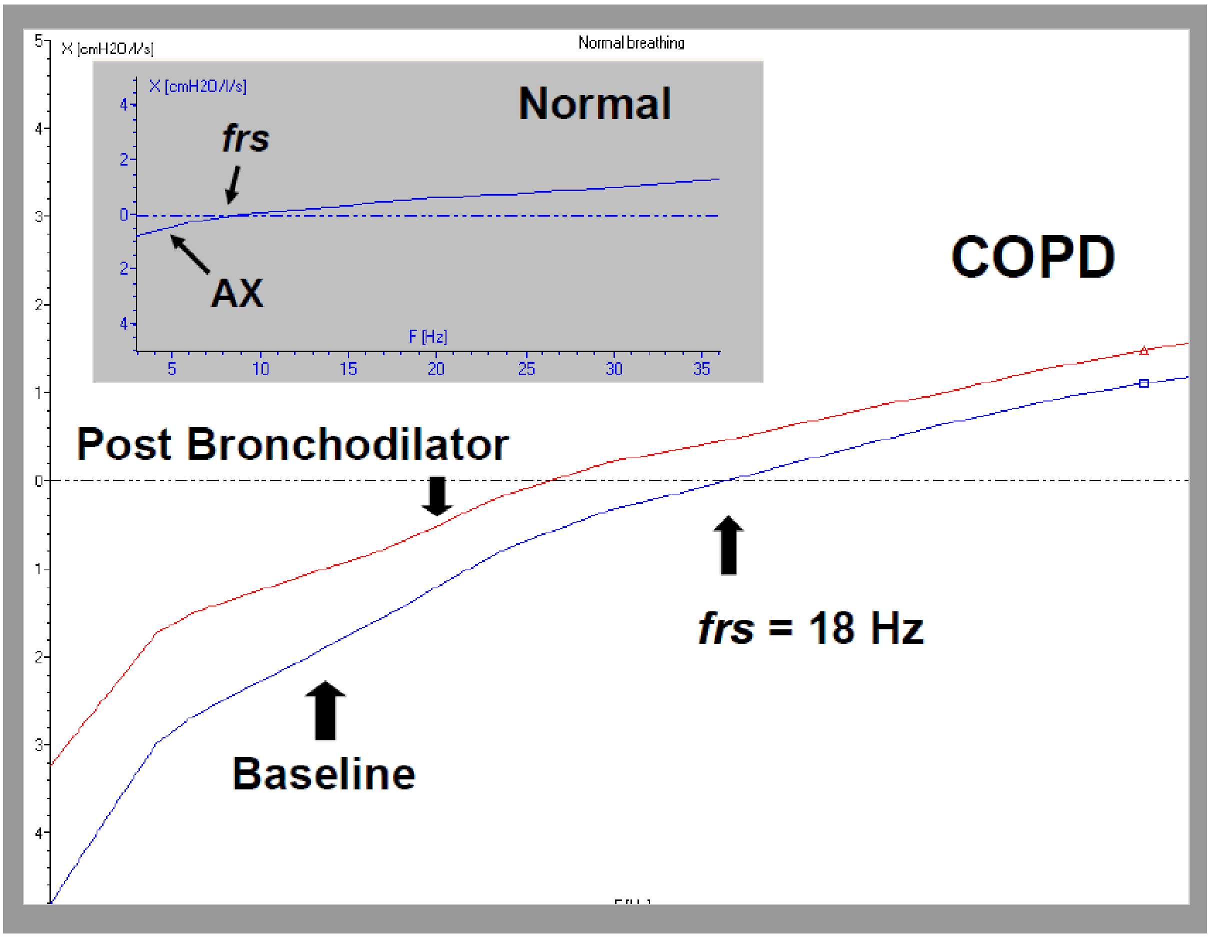

Figure 7 COPD patients have an increased resonance frequency, that decreases after the application of Bronchodilator.

Goal:

Simulate the FOT when the excitatory pressure signal is a multisinusoid. Estimate the real and imaginary part of the complex respiratory impedance, and diagnose the status of two patients: one of them healthy and the other one with COPD.

Dataset

- Pressure and Flow Signals for two subjects. Signals are recorded in apnea conditions, so breath signal is not present.

For each file, we have three variables:

- First column: Time in seconds.
- Second column: Pressure in cmH2O
- Third column: Flow in L/s

Procedure

1) Download the template script to facilitate the required computations.
2) Download the files from campusvirtual. Import them into R studio. You can either use the GUI or alternatively you can use read.csv (set up the condition *header=FALSE*)
3) Plot the excitation signal (pressure) vs time. You can use the base R function *plot*. Investigate how to properly define the axis labels. Select line type 'line'.
4) Plot the flow signal for both subject's vs time. To overlay two lines in the same plot you can use the base R function *lines.* Do you observe any difference in flow for both patients? Which one has a higher flow?
5) Now we are going to compute the Fourier Coefficients for both the input and output signals for both subjects. We are going to assume that the fundamental period is 1 second. Inspect the input and output signals to observe that in fact (except for noise) the signals repeat every second. We will use the exponential form of the Fourier series. Therefore, the Fourier coefficients are complex numbers, and frequencies run from negative values to positive values. We are going to explore the range -30 to 30 Hz. Use the provided code to estimate the Fourier coefficients. Observe how the integral of the Fourier coefficients is computed numerically. Plot the modulus of the Fourier coefficient vs frequency in Hz (Explore 'complex' in the help line). What are the frequencies chosen for the excitation of the respiratory system? Are the main frequencies the same in the input and output signals? Why?
6) Select the main coefficients (they should be 6) and synthesize the input signals using the Fourier synthesis formula. Compare with the empirical one using a plot. Do you expect the new signal to have more or less noise than the empirical one? Why?.
7) For these six coefficients compute the complex impedance by dividing the Fourier coefficients of the pressure signal by those of the flow signal.
8) For the selected frequencies plot the real and imaginary part of the complex respiratory impedance. By comparison with the information already provided can you guess which subject has COPD and which one is healthy?

References

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