Practical: Sampling and spectrum
3 hours

In order to be prepared for this practical it is vital that you first do the self-study assignment "Recording Physiological Signals".

Background

In biomedical research signals that are generated by the human body are recorded. Such signals are called physiological signals. Examples are the electrocardiogram (ECG), blood pressure, and the force generated by muscles.

In this practical you will learn how to record physiological signals into the computer. You will learn how to choose an appropriate sample frequency, and what will happen if you use the wrong sample frequency. Furthermore, you will learn how to analyse signals on the computer. We will start by recording signals generated by a signal generator, and subsequently you will record your own voice and your blood pressure.

As you need special equipment in this lab class you can only do this lab class at the scheduled time. You can, however, download the program Signal that is used to record and analyse the signals to your home computer from http://www.ecgsim.org/education/signal. Obviously you cannot record new signals on your home computer (as you probably don't have an AD-converter connected it), but you can use the program to view and analyse the signals recorded during the lab class.

The content of this practical in included in the Research exam at the end of Q2. The practical skills will be part of the skills test in Q6.

Literature

Oosterom A van, Oostendorp TF: Medische Fysica.

Instructions

You will have to do this practical in pairs (one to provide the signal, and another to control the experiment). Follow the instructions below, and don't hesitate to ask the teacher for assistance.

It is a good idea to make notes in a Word file, and use copy-paste to insert the relevant plots into these notes (you can use Ctrl+C to copy the signal that is displayed, and then paste into Word).

A Sampling a signal

A.1 Choosing the correct sample frequency

The computer is connected to combined amplifier/AD-convertor, that converts an analogue signal to digital values that can be stored in the computer. This process is called *sampling*. When sampling a signal, we have to choose how many sample to take per second (the *sample rate* f_{sam}).

We will start with a sine wave of 200 Hz, generated by a signal generator. We will record the signal 10 samples per period.

1. What sample rate will we need to achieve this?

We will use an amplifier with built-in AD-convertor (figure 1) to record the signal. Strict safety measures are required for amplifiers that are used to record signals from electrodes at the human body. A short circuit in the computer to which the amplifier is connected might result in 230 V appearing at the back side of the amplifier. The amplifier we are using is a patient-safe amplifier, which means it prevents strong currents to flow from the backside (which is connected to a computer) to the front side (which is connected to the patient). This is a requirement for devices connected by electrodes to humans.

Figure 1. Patient-safe amplifier with built-in AD-convertor.

The signal generator is an unsafe device, which we will connect to the safe side om the amplifier. In order to maintain patient-safety, we will use a special adaptor (figure 2) between the signal generator and the amplifier.

Figure 2. Adapter to connect unsafe devices to the safe side of the amplifier.

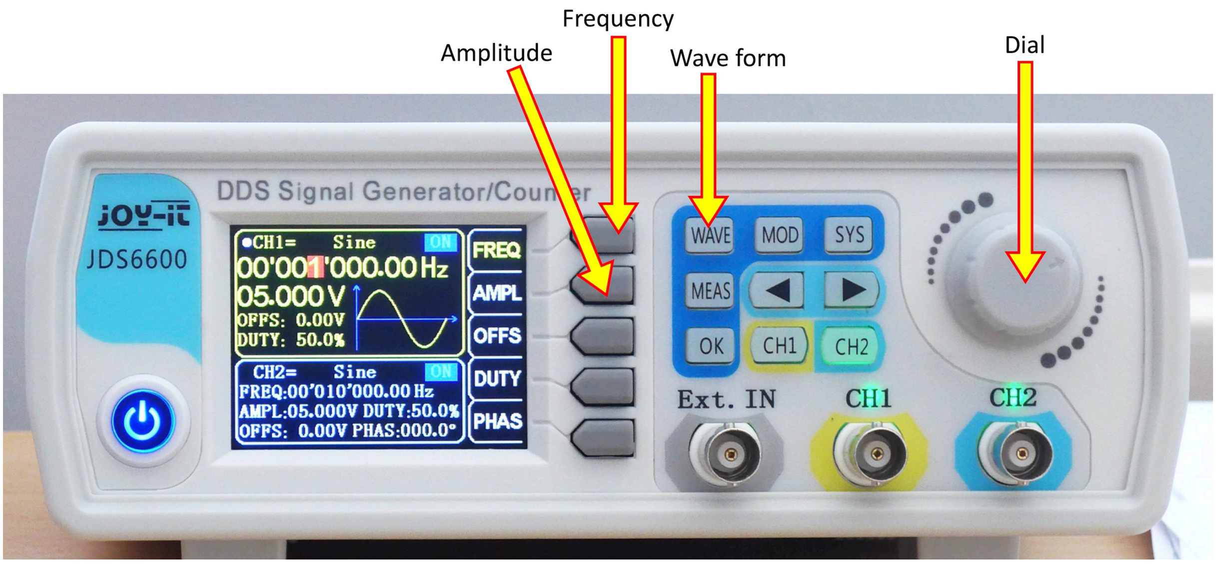


Figure 3. Function generator.

Figure 3 shows the function generator we will use. We will set it to generate a sine wave of 200 Hz. This is how to do that:

- To generate a sine wave: press the WAVE button (arrow Wave form in figure 3), and then use the grey arrow-shaped buttons to the right of the screen to select a sine wave.
- To set the frequency:
    - Use the buttons to the right of the screen to select FREQ (arrow Frequency).
    - The large dial at the right (arrow Dial) changes the digit indicated by the red cursor. You can move the cursor by using the ◀ and ▶ buttons. Use this to set the frequency to 200 Hz.

You won’t need any of the other buttons; best leave them alone to avoid weird settings.

Connect output CH1 of the function generator to input CH1 of the amplifier. We will use the program Signal.exe to record and analyse signals. **You can find this program in the folder Signal on the Desktop. Do not use the Windows start menu to search the program, that will find a different one**. The folder Signal on the desktop contains different versions of the program, for different purposes. Start the plain version called Signal.

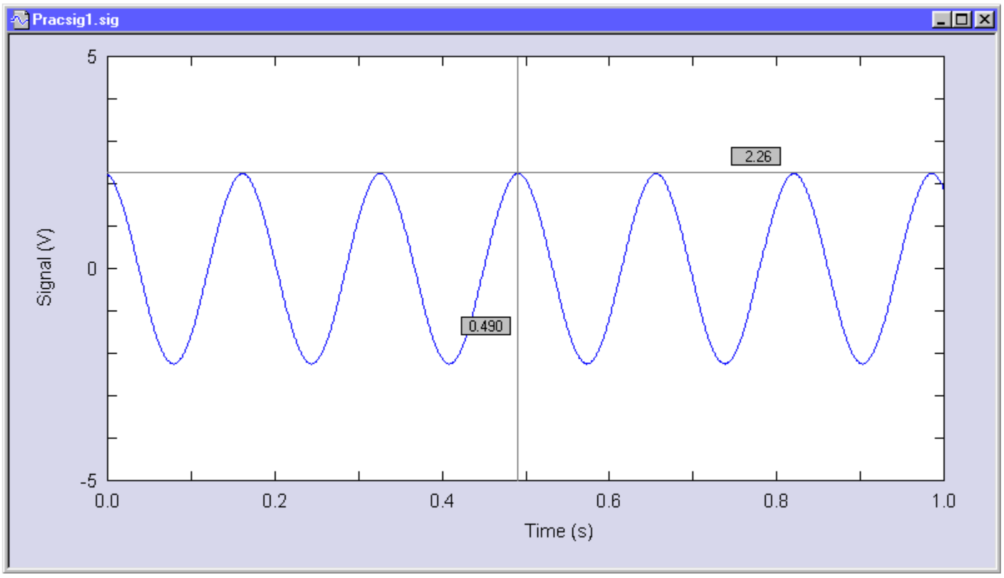
Start the program, and choose File, New (or click on the empty sheet button in the toolbar). The “Preview” window will appear. This displays the signal that is currently presented at channel 1 (CH 1) of the amplifier, and lets the user choose the settings for the recording. Set the recording duration to 1 s, and the sample rate to the value you have computed. Set the input range of the amplifier (top-left) to ±500 mV.

As you will learn later on, physiological signals cannot be recorded without prior filtering to remove the constant voltage that is generated by the electrode-skin interface. For this, all amplifiers that measure these signals have so-called AC-coupling (i.e: they apply a high-pass filter to the signal before recording; AC=Alternating Current). In this practical, we don’t want to apply any filtering. To achieve this, set the hardware filter to DC-coupling (i.e: no filtering is applied).

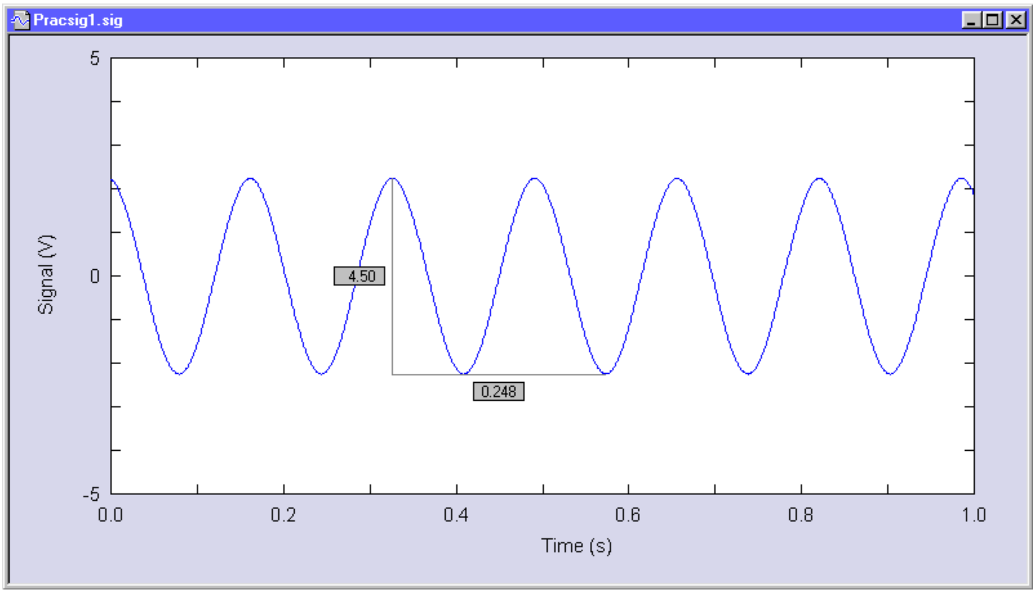
You can set the amplitude of the sine wave the generator produces by choosing AMPL at the right of the screen. Adjust the amplitude such, that the sine wave fills the Preview window considerably without clipping. Then press start to initiate the recording. The computer will now sample the signal and display the result in a new window. Save the recorded signal when the recording is completed.

The window displays the complete signal, i.e. about 200 periods. This is too much to get a proper view of the signal. Select a part of the signal, and use the Zoom-button to display the selection. Repeat this until some 5 to 10 periods are displayed.

If you right-click, rules appear that you can use to measure time and voltage values:



You can measure time and voltage intervals by using control-right-click, and then drag the mouse. A pair of rules will appear that measure the interval from where you started to the new position:



Measure the period of the signal, and record that in table 1 together with the other properties.

samples per period	Sample rate (f_{sam})	Signal frequency (f_{sig})	Filename	Quality of recording

Table 1. Time domain

Make two additional recordings, one with 5 samples per period, and one with 25 samples per period. Subsequently display all three recordings simultaneously:

- Set the zoom value so that about 5 to 10 periods are visible in all recordings;
- Use Window, Tile to display them together;
- Make sure all three recordings are displayed in the same time scale.

2. What is the influence of the sample frequency on the quality of the recording?
3. What would be the proper sample rate for a sine wave of 2 kHz?

As a rule of thumb, we can conclude that for good quality recordings we need:

Sample rate = at least 10 times the (maximum) signal frequency

The qualifier “maximum” refers to the fact that signals may contain multiple components with different frequency. We will look into that later on in this practical.

A.2 Spectrum

Until now we have observed a signal that was a pure sine wave. Obviously, not all signals are pure sine waves.

Figure 5 displays two ways to represent the same signal. This signal consists of a fundamental ('grondtoon' in Dutch) of 10 Hz and an amplitude of 1, a harmonic of 20 Hz and amplitude 0.5, and a harmonic of 40 Hz and amplitude 0.3.

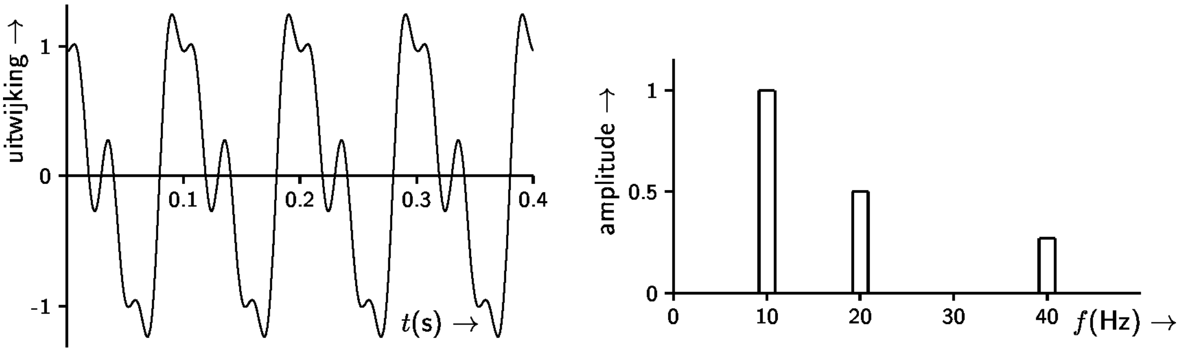


Figure 5. The same signal in time domain (left) and frequency domain (right).

The left panel displays the signal as a function of time, and the right one the signal strength as a function of frequency (the *spectrum* of the signal). The left representation is called the *time domain*, and the right one the *frequency domain*. The program Signal computes the spectrum by a procedure called "Fourier Transformation".

Choose the recording with 25 samples per period. Unzoom so that the complete signal is on the screen (the more signal, the more accurate the spectrum can be determined). In the menu, choose Analyse, Fourier Transform. The program will show the spectrum in a separate window.

4. Does the spectrum look like you would expect?
5. Determine the signal frequency from the spectrum. Is this consistent with the signal period you measured earlier?
6. Until what frequency does the horizontal axis of the spectrum run?

The fact that the largest frequency in the spectrum is half the sample rate is a characteristic of the Fourier transform and no coincidence: in order to determine the frequency of a signal, one needs at least two samples per period (which kind of makes sense). This leads us to another conclusion: in order to determine the frequency of the signal we need:

Sample rate = at least 2 times the (maximum) signal frequency

A.3 Aliasing

In this section, we will investigate what happens if we set the sample rate lower than twice the signal frequency. We will see that in that case something worse happens than that the signal is not recorded: a “ghost signal” that isn’t even present in the signal will appear in the recording. This ghost signal is called an *alias*.

Record three signals, for every one using a duration of 10 s and a sample rate of 200 Hz:

- a sine wave of 40 Hz;
- a sine wave of 80 Hz;
- a sine wave of 120 Hz;

Produce the spectra of these three recordings, and use Window, Tile to display the together.

7. Has the correct frequency been found in all cases?

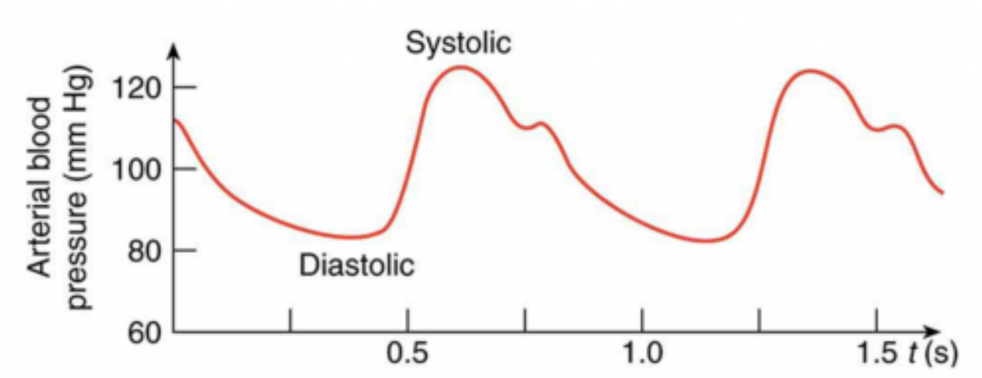


Figure 6. The blood pressure signal.

Figure 6 displays the blood pressure in peripheral arteries as a function of time.

8. Would you agree that a sample frequency of 100 Hz is enough to record this signal?

Suppose you are sampling blood pressure at 100 Hz. A device nearby device generates a signal of 99 Hz, that is picked up by the recording system. Let’s examine what result this would have on the signal.

9. Set the function generator to a frequency of 99 Hz, and record the signal with a sample rate of 1000 Hz to make sure that this indeed a sine wave of 99 Hz.
10. Now record that signal at 100 Hz. How does it look like now? Do you understand why an interference of 99 Hz would not be recognized as interference, but would lead to a wrong conclusion about the blood pressure?

In order to avoid the situation that disturbances may generate “ghost signals” in your recordings it is good practice to feed the signal through an “anti-alias filter” before recording.

This filter removes all components in the signal that have a frequency of more than half the sample frequency. In the next practical, we will study the filtering of signals.

B Recording the human voice

Until now we have recording boring sine wave. In order to obtain more interesting spectra, we will now record the human voice. The highest frequency component within the human voice is 2 kHz.

11. What sample rate do you need to record the human voice?

Connect the microphone to input channel 1 of the amplifier. Sing loud and clear into the microphone, and adjust the input range so that the signal fills a considerable part of the screen, but avoid clipping.

Make the computer ready for a recording of 1 s and the proper sample frequency. Sing a loud and clear, low-pitched, continuous “aa” into the microphone (don’t be shy!). The other student starts the recording. Be aware that the recording only starts at that moment: you have to continue singing for one more second.

12. Zoom in to observe the wave form. What is the period of the signal (i.e: how long does it take before the wave form is repeated)?
13. Produce the spectrum of the signal. What is the fundamental frequency? Note: the fundamental frequency is *not* the strongest component. You can recognize the fundamental from the fact that all frequencies in a harmonic signal are integer multiples of the fundamental frequency.
14. What is the relation between the period of the signal and the fundamental frequency?
15. What is the distance in frequency between the harmonics?

The *pitch* (“toonhoogte” in Dutch) of the human voice is determined by the tension in the vocal cords. The vocal cords vibrate in the same way as a string, generating a fundamental (which is recognized as the pitch of the sound) and a series of harmonics the frequencies of which are multiples of the fundamental.

Record an “aa”-sound, and try to sing it one octave higher than the one you sung before.

16. What are the period and the fundamental frequency of this high pitched “aa”-sound? Compare this to the values for the low-pitched “aa”-sound.
17. What is the distance in frequency between the harmonics?
18. How do you think the human brain recognizes the pitch of a sound?

The shape of the oral cavity determines the *tone* (“klank” in Dutch) of the sound is determined. Depending on the complex, 3D shape of the cavity (which is different for different vowels) certain wavelengths fit well and others don’t. This gives rise to a unique pattern of enhanced and diminished peaks in the spectrum.

Record a “uu”-sound, sung at the same pitch as the low “aa”-sound before.

19. What are the period and the fundamental frequency of this “uu”-sound? Compare this to the values for the “aa”-sound.
20. How do you think the human brain discriminates between “aa”- and “uu”-sounds?