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Simulations of Analog Circuits in Multisim Software Suite

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Abstract: *In the field of Electrical Engineering students' education, the experiments including hardware and software components have an important role. Students mostly gain theoretical knowledge with some or none actual experience, so the development of various simulations if the actual hardware is unavailable can in some part satisfy the need for the practice. In this paper, we elaborated the topic of creating simulations of real analog circuits in Multisim software suite, and their analysis with NI Elvis II+ hardware platform. The students were interviewed about their opinion on these simulations, and their answers confirmed their satisfaction with the realized experiments.*

Keywords: *analog circuits; hardware simulations; Multisim; NI Elvis II+; software simulations;*

1. INTRODUCTION

Every theoretical analysis of the systems can be complicated for the students of engineering if they are not familiar with software simulations of these systems or actual hardware components. National Instruments' Multisim software package is easy to use and achieves real time simulation of analog circuits. This software is accompanied by NI Elvis II+ hardware device which can be used in laboratory while exercising the simulations, measurements, and designs of real life systems. The aforementioned device, together with LabVIEW and Multisim, can be used as an excellent replacement for many other laboratory devices, such as digital multimeters, oscilloscopes, Bode analyzers, function generators, etc. The idea of the experiments given in this paper is to familiar students with certain analog circuits' mode of operation. Furthermore, they are meant to provide an answer to question if the software simulations are sufficient compared to actual hardware simulations, and to facilitate the study and understanding of theoretical concepts of these circuits.

2. ANALOG CIRCUITS

The students throughout their entire education get in touch with the systems comprised of analog circuits, and that's the reason for studying these circuits. Since passive and active electronic elements are relatively cheap nowadays, the exhibition exercises with real circuits are feasible, involving the students' activities regarding the oscilloscope measurements and tracking of the signals emerging in these systems. For every circuit realized in this paper, whether in Multisim software or with real elements, the passive and active electronic elements were used, such as resistors, capacitors, and operational amplifiers (LM 741 circuits).

2.1. Non-inverting operational amplifier

The schematic of the non-inverting operational amplifier is shown in Fig. 1.

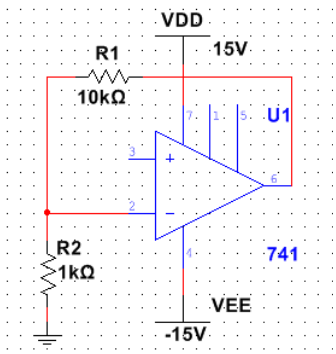

Figure 1. *The schematic of the non-inverting operational amplifier*

The feedback, realized with R_1 and R_2 resistors, returns the signal from output to the inverting input in order to achieve the final gain of the operational amplifier. It is of extreme importance that the gain does not depend solely on the operational amplifier, but on the choice of values for R_1 and R_2. The output signal is in phase with the input signal, and equation that describes gain [1], [2]:

$$A = 1 + \frac{R_1}{R_2} \quad (1)$$

The values of resistors in the selected example are R_1 = 10 kΩ and R_2 = 1 kΩ, so the total gain is then A = 11.

2.2. Low-pass filter

The Fig. 2 shows the schematic of the low-pass filter.

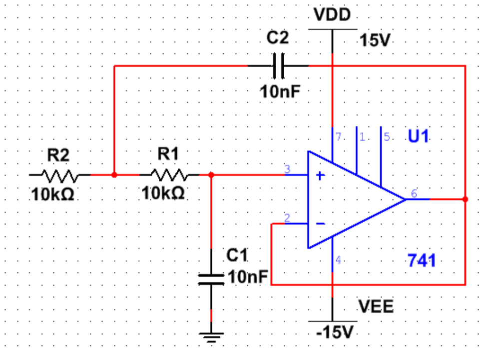

Figure 2. *The schematic of the low-pass filter*

The low-pass filter passes the frequencies lower than the cutoff frequency f_g which is calculated as [1]-[3]:

$$f_g = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \approx 1591.5\,Hz \qquad (2)$$

2.3. High-pass filter

The Fig. 3 shows the schematic of the high-pass filter.

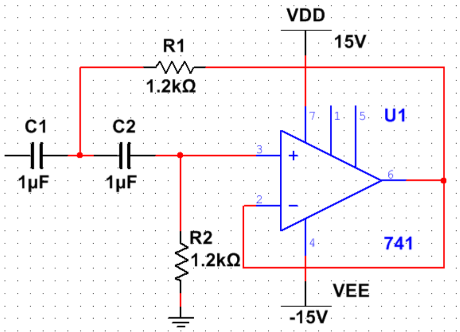

Figure 3. *The schematic of the high-pass filter*

The high-pass filter passes the frequencies higher than the cutoff frequency f_g which is calculated as [1]-[3]:

$$f_g = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \approx 132\,Hz \qquad (3)$$

2.4. Differentiator

The Fig. 4 shows the schematic of the differentiator.

The differentiator is an electronic circuit in which the output voltage is directly proportional to the rate of change (time derivative) of the input voltage [1], [2].

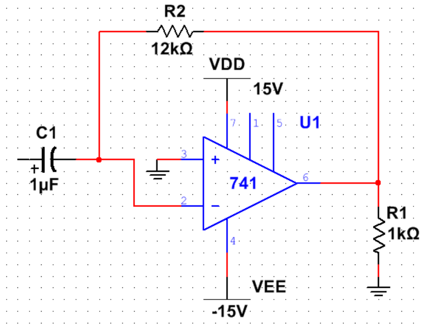

Figure 4. *The schematic of the differentiator*

2.5. Integrator

The Fig. 5 shows the schematic of the integrator.

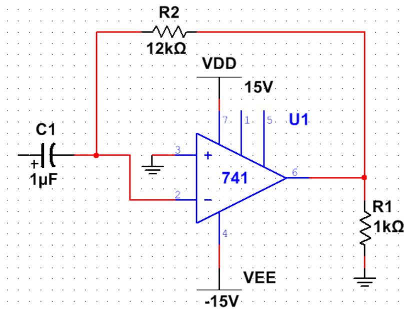

Figure 5. *The schematic of the integrator*

The integrator is an electronic circuit in which the output voltage is directly proportional to the time integral of the input voltage [1], [2].

3. MULTISIM SIMULATIONS

All aforementioned analog circuits are simulated in Multisim software. The realization of the analog circuits is done by interconnecting the basic components, and the simulation can be monitored in virtual oscilloscopes and Bode diagram analyzers [4].

3.1. Non-inverting operational amplifier

The Fig. 6 shows the realization of the non-inverting operational amplifier in Multisim.

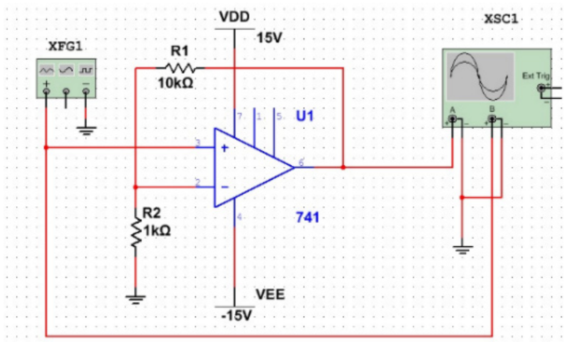

Figure 6. *The realization of the non-inverting operational amplifier in Multisim*

The Fig. 6 clearly shows the function generator and the oscilloscope that is connected to the output of the amplifier and to the function generator. In this way, the oscilloscope will display two signals for their comparison. The oscilloscope display is shown in Fig. 7.

Figure 7. *The oscilloscope display for the non-inverting operational amplifier*

As can be seen from Fig. 7, the oscilloscope displays two signals: (1) output signal from the amplifier, and (2) input signal to the amplifier (function generator signal), with frequency of 100Hz and amplitude of 1 V.

3.2. Low-pass filter

The Fig. 8 shows the realization of the low-pass filter in Multisim.

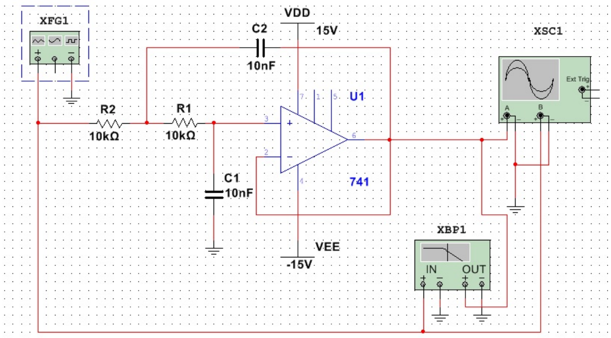

Figure 8. *The realization of the low-pass filter in Multisim*

Along with the function generator and oscilloscope, in order to show the amplitude and phase characteristic of the filter, the Bode analyzer is added.

The Fig. 9 shows two signals: (1) input to the low-pass filter (output from the function generator), signal with frequency of 5000 Hz and amplitude of 2 V, and (2) output of the low-pass filter.

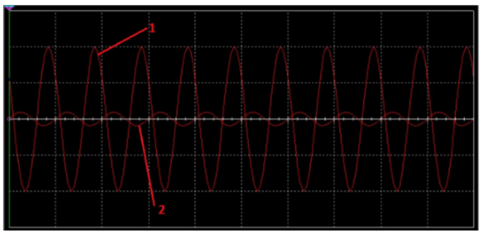

Figure 9. *The oscilloscope display for the low-pass filter*

As can be seen from Fig. 9, the output amplitude characteristic of the filter is significantly lower than the input amplitude characteristic, because the frequency of the input signal is much greater than the cutoff frequency of the filter.

The Fig. 10 shows the amplitude characteristics of the low-pass filter. The blue line intersects with the amplitude characteristic at the point of -3dB and that point represents the filter cutoff frequency. The calculations in (2) showed that the cutoff frequency is 1591.5 Hz, and the Fig. 10 shows that this parameter has the value of 1022 Hz. Thus, it can be said that even though these circuits are simulated, they actually represent the real hardware circuits.

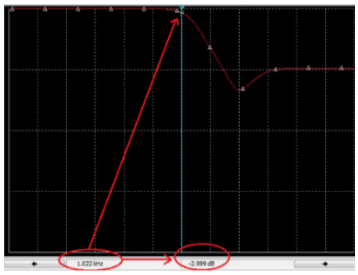

Figure 10. *The amplitude characteristics of the low-pass filter*

The phase characteristics of the low-pass filter is shown in Fig. 11.

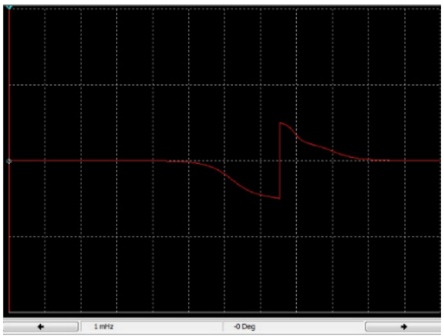

Figure 11. *The phase characteristics of the low-pass filter*

3.3. High-pass filter

The Fig. 12 shows the realization of the high-pass filter in Multisim.

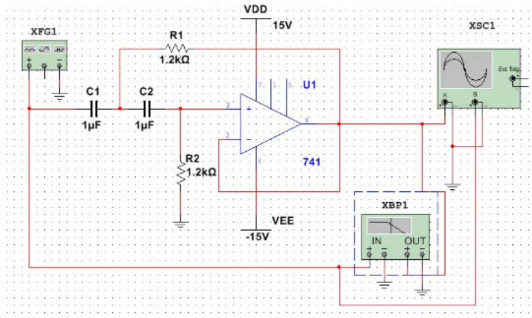

Figure 12. *The realization of the high-pass filter in Multisim*

The Fig. 13 shows two signals: (1) input to the high-pass filter (output from the function generator), signal with frequency of 50 Hz and amplitude of 2 V, and (2) output of the high-pass filter.

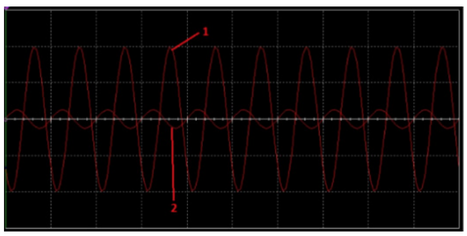

Figure 13. *The oscilloscope display for the high-pass filter*

As can be seen from Fig. 13, the output amplitude characteristic of the filter is significantly lower than the input amplitude characteristic, because the frequency of the input signal is much lower than the cutoff frequency of the filter.

The Fig. 14 shows the amplitude characteristics of the high-pass filter. The blue line intersects with the amplitude characteristic at the point of -3dB and that point represents the filter cutoff frequency. The calculations in (3) showed that the cutoff frequency is 132Hz, and the Fig. 14 shows that this parameter has the value of 210Hz which again signifies the imperfection of the hardware elements and the realistic simulation.

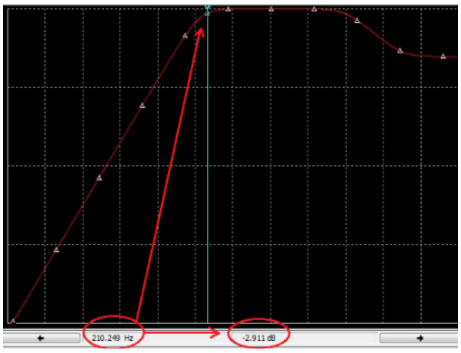

Figure 14. *The amplitude characteristics of the high-pass filter*

The phase characteristics of the high-pass filter is shown in Fig. 15.

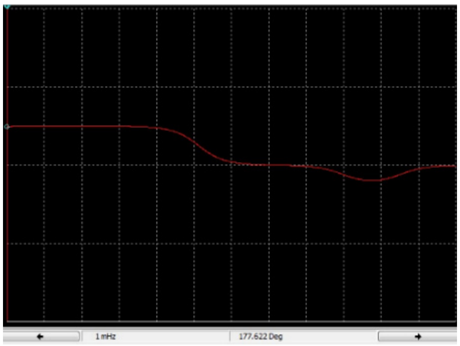

Figure 15. *The phase characteristics of the high-pass filter*

3.4. Differentiator

The Fig. 16 shows the realization of the differentiator in Multisim.

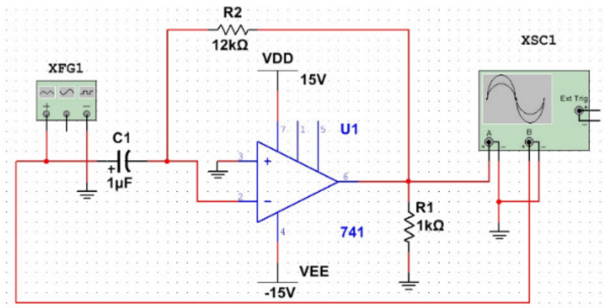

Figure 16. *The realization of the differentiator in Multisim*

The input signal is sawtooth wave and has the frequency of 1000 Hz and amplitude of 7 V. Duty cycle is 50%. The output signal is square wave and this is shown in Fig. 17 that shows the oscilloscope readings.

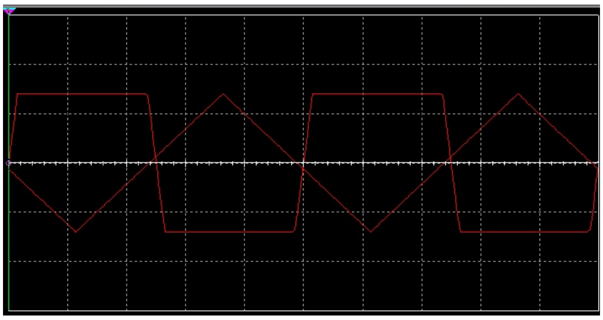

Figure 17. *The oscilloscope readings of the differentiator circuit*

3.5. Integrator

The Fig. 18 shows the realization of the integrator in Multisim.

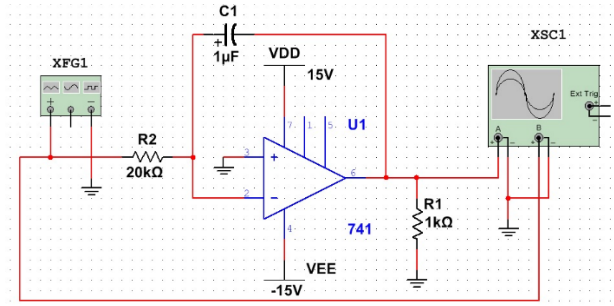

Figure 18. *The realization of the integrator in Multisim*

The input signal is square wave and has the frequency of 50 Hz and amplitude of 10 V. Duty cycle is 50%, and the rise/fall time of the input signal is 10ns. The output signal is sawtooth wave and this is shown in Fig. 19 that shows the oscilloscope readings.

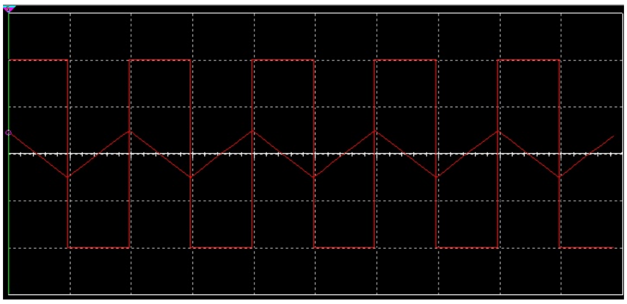

Figure 19. *The oscilloscope readings of the integrator circuit*

4. The simulations with NI Elvis II+ hardware device

The here mentioned simulations are realized with NI Multisim software tool and with real hardware elements, tested on NI Elvis II+ platform. With this in mind, the educational board is developed. It incorporated one operational amplifier with passive elements (resistors and capacitors). The layout of the board is shown in Fig. 20.

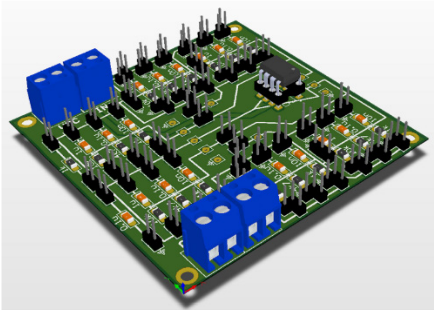

Figure 20. *The layout of the educational board for implementation of the analog circuits*

NI Elvis has provided the oscilloscope, as well as the function generator, Bode analyzer, and operational amplifier power sources. The Elvis II+ platform is shown in Fig. 21.

Figure 21. *The NI Elvis II+ platform*

The platform is connected to the PC via USB and all the measurements are displayed on the computer using the virtual instruments. During these measurements, the function generator signals are passed through analog circuits using the embedded functionalities of the platform. The appearance of the virtual instrument for the function generator control is shown in Fig. 22.

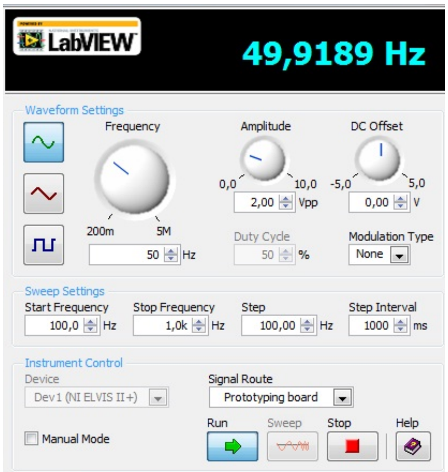

Figure 22. *The NI Elvis function generator layout*

4.1. Non-inverting operational amplifier

The analysis of the non-inverting operational amplifier is made with the real circuit and the characteristics of the input and output signals are shown in the Fig. 23. As with the simulated circuits, the voltage and the frequency of the input signal are remained unchanged. The green line represents the input signal, and the blue line the output signal.

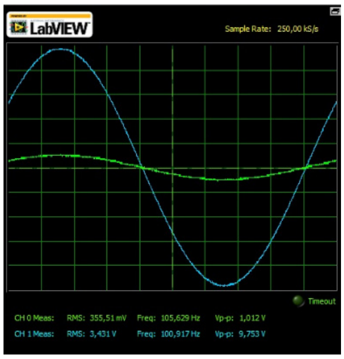

Figure 23. *The oscilloscope reading from the non-inverting operational amplifier circuit*

4.2. Low-pass filter

The characteristics of the input and output signals of the low-pass filter circuitry are shown in the Fig. 24. The green line represents the input signal, and the blue line the output signal.

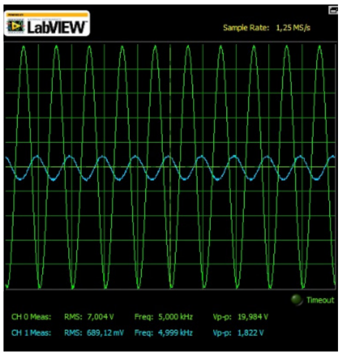

Figure 24. *The oscilloscope reading from the low-pass filter circuit*

The amplitude and phase characteristics of the low-pass filter using Bode analyzer is shown in Fig. 25.

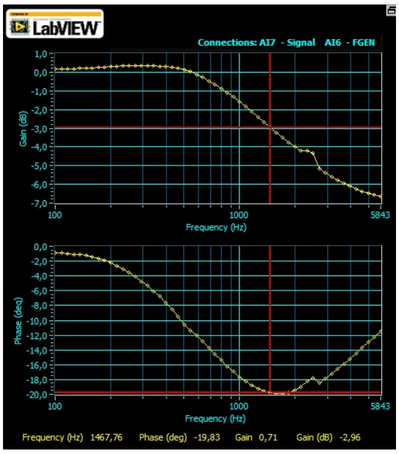

Figure 25. *The amplitude and phase characteristics of the low-pass filter*

At -3dB the cutoff frequency is approximately 1478Hz, which is relatively good result considering that this cutoff frequency is closer to the calculated frequency.

4.3. High-pass filter

The characteristics of the input and output signals of the high-pass filter circuitry are shown in the Fig. 26. As with the low-pass filter, the signals with frequencies out of filtering range are weakened. The output signal (blue line) is significantly lowered compared to the input signal (green line).

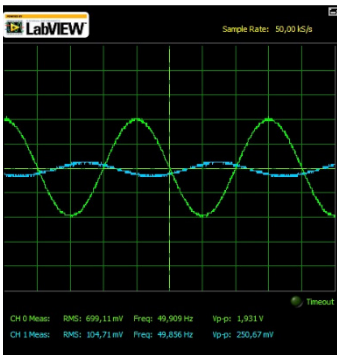

Figure 26. *The oscilloscope reading from the high-pass filter circuit*

The amplitude and phase characteristics of the high-pass filter using Bode analyzer is shown in Fig. 27. It can be seen that the cutoff frequency is approximately 178 Hz, which is also better than the simulated circuit, and the deviation from the real, calculated frequency, isn't so big.

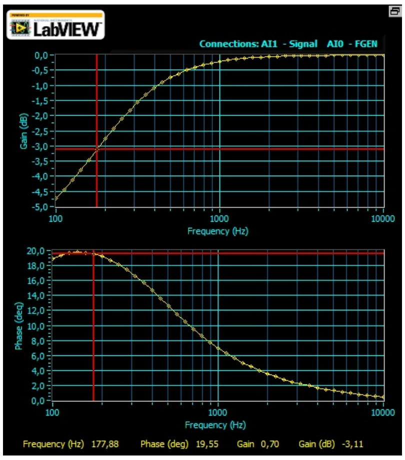

Figure 27. *The amplitude and phase characteristics of the high-pass filter*

4.4. Differentiator

The input signal is sawtooth wave (green line), and the output signal is square wave (blue line), same as with the Multisim simulation. The both signals are shown in Fig. 28.

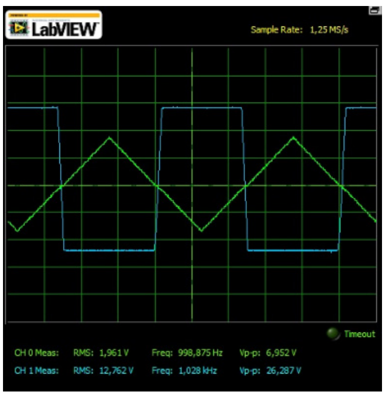

Figure 28. *The oscilloscope reading from the differentiator circuit*

4.5. Integrator

The input signal is square wave (green line), and the output signal is sawtooth wave (blue line), same as with the Multisim simulation. The both signals are shown in Fig. 29.

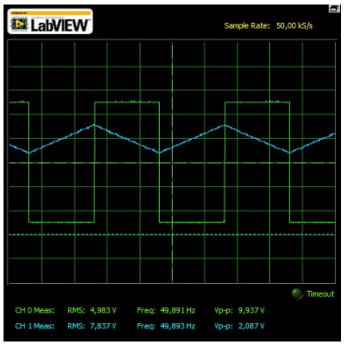

Figure 29. *The oscilloscope reading from the integrator circuit*

5. The student analysis

In order to better understand the here mentioned circuits and simulations, the students from the departments of the Power Engineering and the Computer Engineering were interviewed.

5.1. Survey on the students of the Power Engineering

The questions that the students of the Power Engineering were asked were related to the application of the real hardware experiments and whether along with hardware experiments the software experiments are needed as well. The total of 18 students was interviewed and the topics were as follows:

1. The visualization of the theoretical concepts in the Signal and Systems course using hardware platforms is fine.
2. The hardware simulations have helped me to improve my knowledge from the Signal and Systems course.
3. Along with hardware platforms, the software experiments simulating real devices are needed as well.
4. Along with hardware platforms, the simulations in a software suite are needed as well.
5. In your opinion, what should be the ratio between the software simulation experiments and experiments with real hardware devices?

The students were able to respond to these topics by selecting one of the following statements (applied to topics 1-4):

(1) Strongly agree,
(2) Somewhat agree,
(3) Neither agree nor disagree,
(4) Somewhat disagree,
(5) Strongly disagree.

For the fifth topic, the students ought to choose one of the following given answers:

- The software simulations should have precedence over hardware simulations;
- The software simulations should have equal status with hardware simulations;
- The hardware simulations should have precedence over software simulations;
- I don't know.

5.2. Survey on the students of the Computer Engineering

The main subject in this survey were software simulations and whether the hardware experiments are needed as well. The interview included the following topics:

1. The visualization of the theoretical concepts in the Signal and Systems course using software platforms is fine.
2. The software simulations have helped me to improve my knowledge from the Signal and Systems course.
3. Along with software platforms, the hardware experiments with real devices are needed as well.
4. Along with software platforms, the simulations in hardware platforms are needed as well.
5. In your opinion, what should be the ratio between the software simulation experiments and experiments with real hardware devices?

The answers to these questions were given the same as for the students of the Power Engineering.

5.3. Survey results and discussion

The Fig. 30 shows the results of the survey for the students of Power Engineering. The total of 18 students were interviewed. The question rank was calculated in a way that the answer "Strongly agree" had a score of 5, descending to a score of 1 for the answer "Strongly disagree".

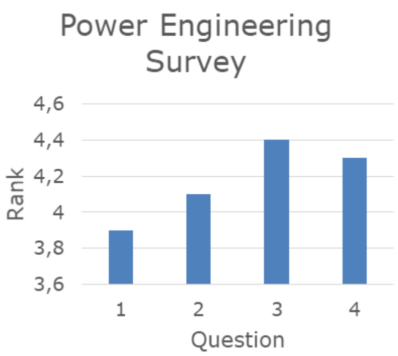

Figure 30. *Power Engineering students' survey results for the questions 1 - 4*

As can be seen from Fig. 30, the students of Power Engineering mostly agreed with the third question, and mostly disagreed with the first question. The students in general agree with the statement that laboratory exercises are needed. The survey got good results, since all answers tend to the upper limit. The answers to the fifth question are given in the Fig. 31.

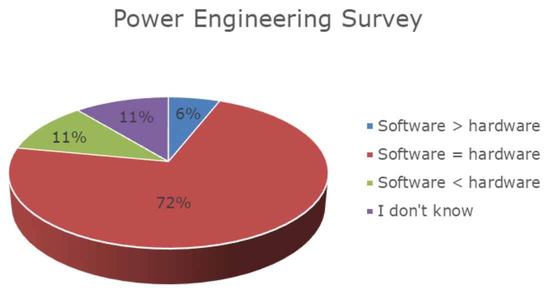

Figure 31. *Power Engineering students' survey results for the fifth question*

The students clearly expressed the desire that both hardware and software experiments have the equal ratio.

The Fig. 32 shows the results of the survey for the students of Computer Engineering. The total of 26 students were interviewed. The question rank was calculated in the same way as before.

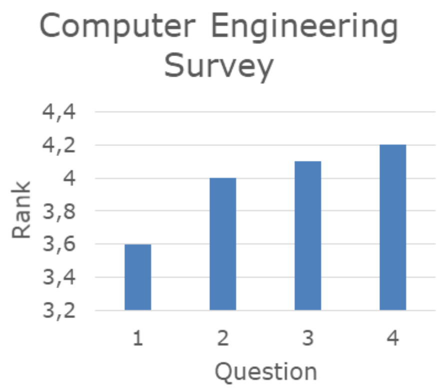

Figure 32. *Computer Engineering students' survey results for the questions 1 - 4*

As can be seen from Fig. 32, the students of Computer Engineering mostly agreed with the fourth question, and mostly disagreed with the first question. The students in general agree with the statement that laboratory exercises are needed. The survey got good results, since all answers tend to the upper limit. The answers to the fifth question are given in the Fig. 33.

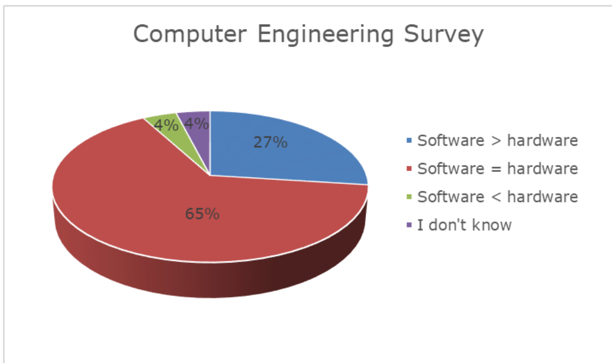

Figure 33. *Computer Engineering students' survey results for the fifth question*

The students clearly expressed the desire that both hardware and software experiments have the equal ratio, like their colleagues. However, the students of Computer Engineering expressed greater desire to have more software than hardware simulations (27%, compared with only 6% for the Power Engineering students). This result is somewhat anticipated, since the students of Computer Engineering have more software courses in their curriculum.

6. CONCLUSION

The students of Electrical Engineering nowadays have more theoretical knowledges than practical ones in the subjects of their primary interests. This is the motivation for this paper, to give the students more hands-on experience with real hardware devices and their usage through hardware and software simulations.

Several experiments were realized that used actual hardware components, NI Elvis II+ platform, and NI Multisim simulation software. All experiments were conducted successfully. The students of Power Engineering and Computer Engineering were interviewed about their view on these experiments. As it turned out, students gave positive feedback on these simulations, and answered that they would need almost equal amount of software simulations and experiments with actual hardware devices. This was the result that was anticipated and we'll gladly move on with bringing some more experiments for students' practical exercises.

ACKNOWLEDGEMENTS

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