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Integration of Virtual and Hands-on-Laboratory Experience in Learning of Filtering Concepts

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Abstract – ***Better understanding of the acquired theoretical knowledge in the field of digital signal processing, for their successful use in future engineering practice, is achieved by introducing interactive virtual and hands-on laboratory experiments. In this paper we present realization of LabVIEW virtual interactive DSP experiments and hardware DSP laboratory experiments on the NI-ELVIS II + development platform as a part of our ongoing efforts in DSP laboratory development. These experiments can be used in the DSP lab for "visualization" of filtering concepts. For the purpose of "visualization", LabVIEW filter palette has been used for the virtual experiment of band pass digital filter design and active band pass filter has been realized on hardware developing platform NI-ELVIS II+, for the purpose of hands-on DSP experiments. Theoretical characteristics of active band pass filter validated by measurements on realized hardware model. Pedagogical issues concerning meeting different learning styles through integration of virtual and hands-on laboratory experiments in DSP laboratory are elaborated. The traditional approach of teaching engineering concepts that comes as the combination of classroom teaching and homework exercises, lacks the student's intuition for applying same concepts to different new problems. The integration of virtual and hands-on laboratory experience in addition on theoretical filtering concepts creates the perfect match for improving student practical skills. On the basis of mixture of virtual and hands-on exercises and web-based teaching materials, blended delivery mode of DSP course is enabled.***

Keywords: ***band pass filter, filter characteristics, virtual experiments, hardware development platform, visualization of DSP theory, learning styles, blended course***

I. INTRODUCTION

As a rule, learning basic theoretical concepts of signal and system analysis and synthesis is difficult for the students of engineering. This difficulty is a result of the gap between understanding mathematical formalisms of these concepts and student's abilities to connect these theoretical concepts with practical engineering applications. In the aim of solving this problem many "recipes" suggest "visualization" of digital signal processing theory [1].

MATLAB software package has become standardized and inevitable way of "visualization" of DSP theory for a long time. Many MATLAB based DSP "visual experiments" are constituent parts of lectures and practical exercises at the courses of system and signal theory and digital signal processing [2], [3], [4]. Ability of programming in MATLAB is the skill which is acquired by students at the beginning of their Electrical Engineering studies.

However, all that can be done with MATLAB based on DSP "virtual experiments", in simpler way, without writing lines of program code, and it can also be done with using software package LabVIEW (Laboratory Virtual Instrument Engineering Workbench). LabVIEW is graphic developing environment with built-in functionality for simulation, data acquisition, instrumentation, measurement analysis and data presenting. User's interface for some application is created without any code line, with simple "drag-and-drop" of pre-defined objects [5]. Graphic applications created in LabVIEW are called virtual instruments (VI), as their look and functions "imitate" real instruments: oscilloscopes, voltmeters, ammeters, function generators, etc. [6]. LabVIEW contains a great number of library functions which are used for creating applications for solving set of standard tasks from the field of digital signal processing, such as: DFT and FFT transform, presentation and analysis of signals in spectral and time domain, analogue and digital FIR and IIR filters, multirate filters, etc. LabVIEW filter palette possesses range of tools for synthesis and analysis of filters [5] (Fig.1).

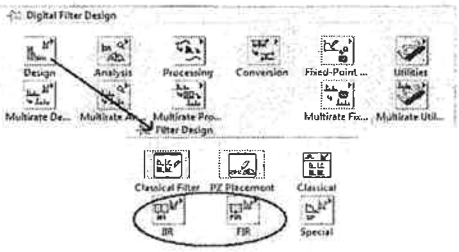

Fig. 1. LabVIEW filter palette

However, modeling and simulation in virtual laboratory environment of MATLAB and LabVIEW cannot completely prepare students of Electrical Engineering for work with hardware equipment and real experiments needed for designing, testing and running of practical engineering applications.

The aim of hardware laboratory experiments in education of engineers through "physical contact with hardware" also means better understanding of acquired theoretical knowledge in order to apply it more successfully in future engineering practice.

So, hands-on experiments with hardware equipment and real instruments are necessary to integrate with virtual experiments in DSP laboratory that seem to students as they work under real-world conditions.

Hardware lab experiments for "visualization" of DSP theory is possible to realize even without a laboratory which often demands expensive hardware for digital signal processing. Instead of expensive and "bulky" lab equipment in DSP lab it is more appropriate to use National Instruments (NI) LabVIEW software package in combination with NI-ELVIS II+ hardware developing platform and PC.

National Instrument Educational Laboratory Virtual Instrumentation Suite NI-ELVIS II+ is a hardware developing platform, completely adjusted for software package LabVIEW, by which its usage is easier significantly, on the other hand, it is yet limited to this software package. NI-ELVIS developing platform has numerous abilities which can be applied both in labs at the faculties and in designing professional devices.

Besides standard palette of virtual instruments from LabVIEW, NI-ELVIS enables usage a set of additional virtual instruments (Fig. 2).

Palette contains 12 most often used lab instruments such as oscilloscope, DMM (digital multi meter), generator of functions, Bode analyzer, spectral analyzer, etc. The mentioned VIs are suitable for simple measuring, while for more complex measuring, continual recording of measured data and signal processing it is possible to create new LabVIEW based VI (by using available SubVIs [6]) which would use potentials of hardware platform to the full extent.

Transmission of measured data from developing platform into the computer and vice versa is carried out over USB port which is, unfortunately, a bottleneck of the whole system and limits the speed of hardware's part down to 1.25 MS/s (data refers to oscilloscope).

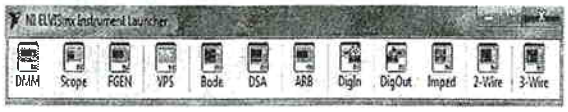

Fig. 2. Ni-ELVIS palette of virtual instruments

Theory of signals and systems and signal processing is studied at Electrical Engineering studies through several courses that are mainly theoretical. With DSP lab experiments which can be realized on hardware developing platform NI-ELVIS II+ and with LabVIEW software which imitates realistically real instruments, students can realize in hardware way and visualize mathematic concepts of filtering in an efficient way. In order to illustrate possibilities of application of LabVIEW and NI-ELVIS II+ developing platform for visualization of theoretical concepts of filtering, some of the measuring carried out by its usage.

Such LabVIEW-based laboratory environment for learning of filtering concepts we introduced at the 6th IEEE International Symposium on Applied Computational Intelligence and Informatics held on May 2011 in Timişoara [7].

This approach of learning DSP concepts has added value from pedagogical standpoint - integration of virtual and hands-on laboratory experiments in addition to theoretical lectures and student's homework could accommodate individual differences in cognitive learning styles of DSP learners successfully.

We have found the labs to be very helpful in aiding student understanding of filtering concepts. Student comments and their better exam passing in this school year indicate that real learning has taken place by using a hands-on lab experience that would have been missed if a purely theoretical approach had been taken.

II. LABVIEW DSP VIRTUAL LABORATORY EXPERIMENTS

The students need to see the results of pocessing – what they see is what they learn best. It is necesary that visual experiment is be highly interactive [8]. LabVIEW has easy-to-use and highly visual GUIs named virtual instruments that built powerfull DSP simulation environment.

Almost all common digital filters design tools are included in LabVIEW.

"Visualization" of the procedure of digital filter design using LabVIEW filter palette is given on the example of obtaining of frequency characteristics for FIR and IIR band pass filter with the following specifications: Lower Pass Band f_{pass1} = 132Hz, Upper Pass Band f_{pass2} = 1561Hz, Lower Stop band f_{stop1} = 30Hz, Upper Stop Band f_{stop2} = 1800Hz (fig. 3), SB attenuation equal 30dB and PB Ripple equal 0,40.

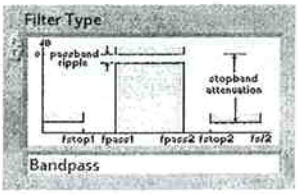

Fig. 3. Band pass filter specifications

Filter input signal is sine wave with frequency 1000 Hz. Sampling frequency is 4000 Hz.

LabVIEW filter pallets are used to obtain phase and magnitude response of FIR and IIR band pass filter. Applied FIR filter design method is windowing (selected window is Kaiser-Bessel). Butterworth Approximation for IIR filter is used.

Obtained FIR band pass filter magnitude and phase response are shown in Fig. 4.

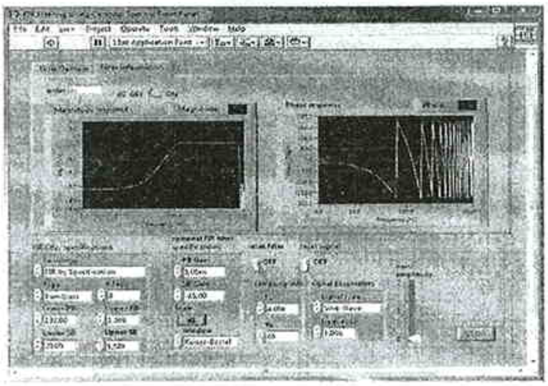

Fig. 4. FIR band pass filter magnitude and phase response

Obtained IIR band pass filter magnitude and phase response are shown in Figure5.

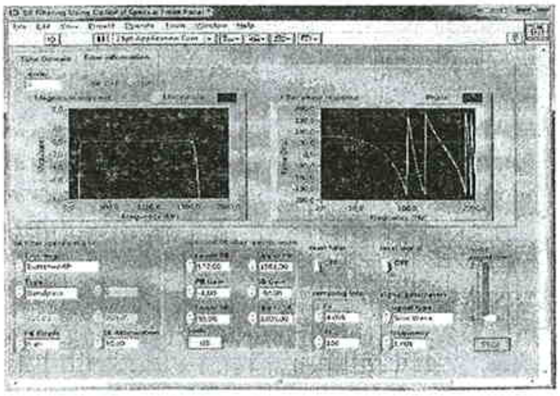

Fig. 5. IIR band pass filter magnitude and phase response

Obtained frequency responses of FIR and IIR filters confirm the known fact that FIR filters require a much higher filter order than IIR filters to achieve a given specifications, but have exact linear phase.

III. DSP LAB EXPERIMENTS BASED ON NI ELVIS II+ DEVELOPING PLATFORM

A simple hardware lab exercise for measuring characteristics of active band pass filter has been realized on a NI-ELVIS II+ developing platform.

By cascade connection of high pass filter (HP filter) and low pass filter (LP filter) it is possible to realize band pass filter (BP filter) and by parallel connection of high pass filter (HP filter) and low pass filter (LP filter) it is possible to realize band reject filter (BR filter). Impulse response of BP filter is obtained by convolution integral of impulse responses of HP filter and LP filter which are cascade connected [9].

Active band pass filter whose electrical scheme is shown in Fig. 6 is realized by cascade of three levels [9]: HP filter, amplifier and LP filter. Each level contains an operational amplifier LM741 which is an active component and resistors as well as condensers which are passive components.

Excitation of filters is carried out by LabVIEW function generator (FGEN).

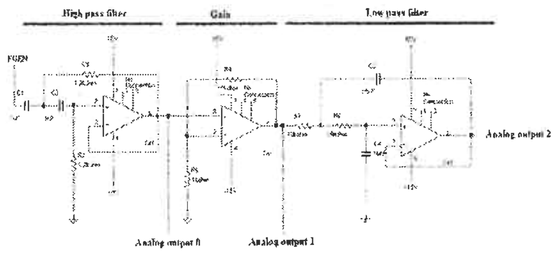

Fig. 6. The active bandpass filter electrical scheme

The first level in the Fig. 6 is high pass filter. Its cutoff frequency is $f_{cvf} = 132.6 Hz$. The second level is amplifier whose gain is A=11. The last level is lowpass filter whose cutoff frequency is $f_{cnf} = 1591.5 Hz$.

Electrical scheme in the Fig. 6 is realized on NI-ELVIS II+ hardware developing platform (Fig.7).

In the aim of illustrating basic filter function - passing signals without attenuation in certain frequency range, using generator of functions at input of FGEN circuit from Fig. 6 signals of different frequencies were brought to.

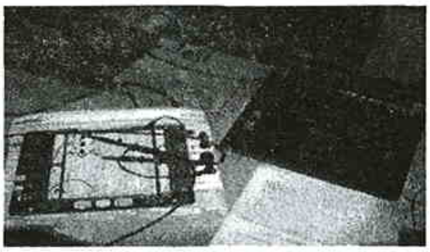

Fig. 7. Realization of BP filter on Ni ELVIS II+ hardware developing platform

The waveform of the signals at input (green curve) and output (blue curve) – analogue output 2 of BP filter are shown on the Fig. 8. Expectedly that high pass filter passes signals whose frequency is lower than its cutoff frequency 136.2Hz with significant attenuation while signals with frequencies higher than the cutoff one are passed without attenuation (Fig. 9). It should be pointed out that the amplitude of the output signal is increased as signal passes through amplifying level.

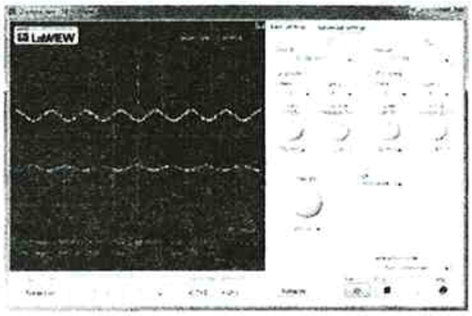

Fig. 8. Waveforms of the signals at input and output of BP filter – frequency of the input signal is lower than f_{cvf} = 136.2Hz

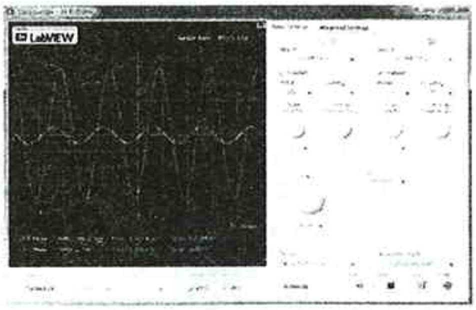

Fig. 9. Waveforms of the signals at input and output of BP filter – frequency of input signal is higher than f_{cvf} = 136.2Hz

By using of Bode analyzer from Ni ELVIS palette of virtual instruments Bode diagrams of realized BP filter were obtained. Bode diagrams for band pass filter with pointed cutoff frequencies are shown in Fig. 10.

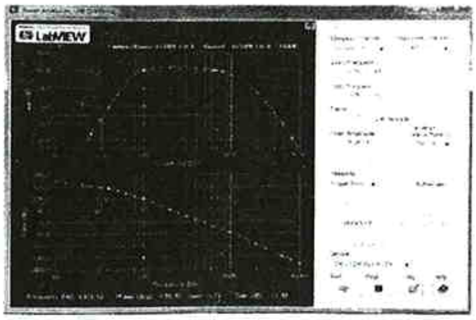

Fig. 10. Bode diagrams for BP filter

By using Dynamic Signal Analyzer from NI-ELVIS palette of virtual instruments spectral characteristics at the output of BP filter were obtained. It is possible choose frequency display to be logarithmic [Magnitude (dB/ms)] or linear [Magnitude (/ms)]. Spectrum of output signal of realized band pass filter is shown in Fig. 11.

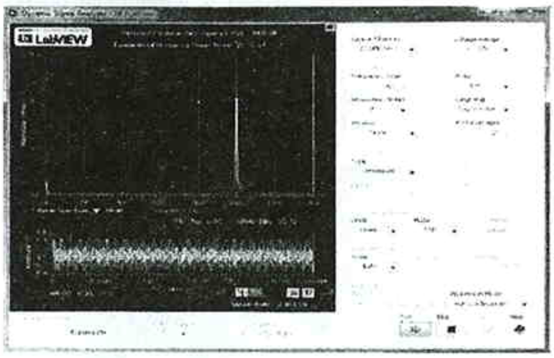

Fig. 11. Spectrum of BP filter output signal

Obtained hardware experimental results validates the theoretical concepts of BP filters designing [10].

IV. INTEGRATION OF VIRTUAL AND HANDS-ON LABORATORY EXPERIENCE -PEDAGOGICAL ISSUE

The engineering studies are well based on the prominent mathematical theories and students are required an extensive understanding and experience on how to apply them to specific engineering concepts. In order to take advantage and apply those concepts with expediency, skills should be learned by repeated applications over a wide collection of test conditions, as it is pointed out in [11].

Individual differences in cognitive learning styles e.g. student's mode of thinking, perceiving, remembering, or problem solving are quite obvious when teaching science or engineering. The variation is reflected in fact that some students need to visualize the task before starting, some approach learning and teaching rather sequentially or rather randomly, some would work quickly or even deliberately, some are passionate of immediate "try in the lab", while others would primarily focus on mathematical structure and find theoretical outputs before real practice. This indicates that multiple approaches are needed to achieve the best for students.

The traditional method of teaching engineering concepts comes as the combination of classroom teaching and homework exercises. Such approach lacks students' intuition for applying same concepts to different new problems. The integration of virtual and hands-on laboratory experience creates the perfect match for improving student practical skills.

In order to accommodate different learning styles, we combined virtual LabVIEW exercises with class exercises based on Matlab and hands-on lab exercises on specific NI hardware in addition on theoretical filtering concepts.

MATLAB software package has become standardized and inevitable simulation tool for "visualization" of DSP theory. Many MATLAB based DSP "visual experiments" are constituent parts of lectures and practical exercises at the courses of system and signal theory and digital signal processing for a long time.

Like MathWorks Inc., and National Instruments offers nowadays plenty of opportunities for incorporating NI hardware and NI LabVIEW software in a classroom and laboratory for teaching and learning DSP. For example, the LabVIEW Digital Filter Design Toolkit [12], built on the LabVIEW graphical development platform, is design interactive tool to view filters in real time as they adjust parameters, to help optimize proposed filters with real-world measurements and parameter sweeps, and to ensure a smooth transition from theory to implementation. Many solved examples and tutorials concerning signal processing & analysis can be finding on the NI Developer Zone web page [13]. It can be useful for performing of lab exercises or student design project. Teacher should foster student teamwork for solving complex DSP design applications regarding simulation of real work engineering environment. Teamwork project tasks could be performed from student's home (virtual experiments) and also as lab exercises on selected hardware platforms.

Such approach is also very convenient for blended courses since web-based teaching materials and virtual experiments can be successfully hosted and delivered through any learning management system. Besides, online tutorials that guide students through the use of the tool and corresponding theoretical concepts are easily included on the course site.

V. CONCLUSION

Laboratory exercises realized with virtual interactive experiments and hardware components are very important in education of engineers. These exercises help them in better understanding of acquired theoretical concepts and applying them successfully in future engineering practice.

One of the "recipe" for the solving the gap between understanding mathematical formalisms of digital signal processing concepts and student's abilities to connect these theoretical concepts with practical engineering applications is "visualization" of DSP theory by using NI LabVIEW software and hardware experiments.

This approach of DSP learning through integration of virtual and hands-on-laboratory experience, in addition to classroom teaching and homework exercises, successfully accommodates individual differences in cognitive learning styles, as outlined in the paper. Since portions of teaching materials, different tutorials and virtual experiments can be successfully hosted and delivered through the web, it is obvious that blended mode of teaching and learning DSP is possible.

A whole range of filter characteristics is possible to be obtained by using LabVIEW and NI-ELVIS II+ palette of virtual instruments as well as by creating the new ones as it is described in the paper. There is a possibility for further extensions of DSP NI LabVIEW performed experiments: to record measured data in the form of data files for further processing. Similar DSP lab experiments could also be realized in MATLAB and then obtained results could be compared and analyzed. DSP lab experiments are possible to realize with the help of FPGA developing platform, as it is planned as a part of further DSP laboratory development.

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