

Teaching Digital Filters using NI LabVIEW and USRP

Aleksandar Atanasković, Biljana Stošić, and Nataša Maleš-Ilić

Abstract – Computer based learning has become an important part of education systems. It provides animation and interactive processes that are not possible with textbooks. Filtering of digital signals is a fundamental concept in digital signal processing. In this paper, a framework for application of NI LabVIEW and USRP in computer based teaching and learning, with a few examples in the domain of digital filtering is described. Real-time communication system demonstrations for the classroom are discussed.

Keywords – Computer-based learning, NI LabVIEW, NI USRP, Digital filters, Real-time visualization.

I. INTRODUCTION

One of the most important parts of engineering education is the application of theoretical knowledge in practice, which can be realized in different ways. Standard experimental set-up for teaching software defined radio (SDR) and related communication system/signal processing topics is expensive, takes a significant amount of time for development, etc. Because of that, the universal software radio peripheral (USRP) based system can be great solution for different topics in real-time.

Digital communications is taught in most electronic degree curricula worldwide, where the main focus is normally the theory of communications and understanding of different building blocks of a communication system. Learning theory is essential for students, but it is not enough to prepare them for marketplace in industry. Hence, this paper introduces the application of Laboratory Virtual Instrument Engineering Workbench (LabVIEW) virtual instruments in electrical engineering education. After explaining the advantages of using LabVIEW [1-2], a few selected examples, typical for digital signal processing [3-4], will be discussed and illustrated. Highlights include the ability to work with signals and different filters to facilitate real-world filter testing.

The USRP family of products has become a popular platform for hardware-based research and test bed validations conducted by universities in SDR field [2], [5-7].

The LabVIEW/USRP combination presents an opportunity to enhance communications education by enabling a low cost, hands-on approach with live signals for realistic, real-world demonstrations, laboratory exercises, capstone design projects, and cutting-edge research.

Among the many software products, LabVIEW as one of the leading products of National Instruments (NI) is the most worthy to solve engineering problems. LabVIEW virtual instrument concept allows to create complex system of information processing which using the isolated blocks, some

unique subprogrammes, virtual instruments (VIs), working with the flow of information. With educational and practical point of view, the main advantages of LabVIEW are the possibility of combining the computer simulation technology, virtual management, and natural data collection. All of these possibilities provide a good reason for inclusion of LabVIEW to student training of the natural sciences and technical specialties.

The rest of the paper is structured as follows. URSP and LabVIEW are shortly introduced in Sections II and III, respectively. Filtering of digital signals by using LabVIEW/USRP combination is presented in Section IV along with the discussion. The paper is concluded in Section V.

II. USRP INTRODUCTION

The USRP [2], [5-7] is a SDR reconfigurable radio frequency (RF) hardware designed to build and test digital communication systems. The USRP is commonly used by researchers as a wireless prototyping platform and by universities as a teaching aid. With support from NI LabVIEW, which is a system-design platform and development environment, real-time processing is made possible. Hence, the availability of both USRP and LabVIEW has benefited various researchers and educators.

Generally speaking in an academic setting, USRP's can be used in courses, laboratories, and researches involving cognitive radio, digital signal processing (DSP), multi-rate DSP, communication systems, Field-Programmable Gate Array (FPGA) system design and implementation, a wide variety of other areas (e.g. homeland security applications, satellite systems, radio astronomy, wildlife tracking, radio frequency identification, medical imaging, sonar systems, and customizable test equipment development).

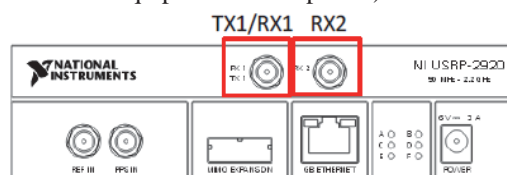


Fig. 1. USRP front panel

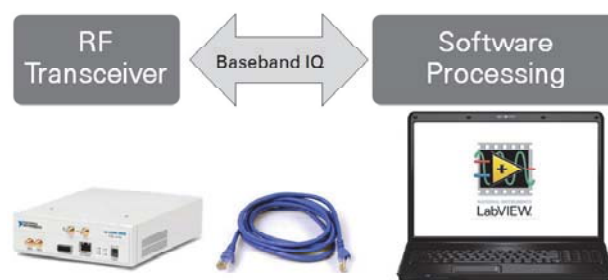


Fig. 2. Simplified overview of a SDR setup built around a NI USRP [2]

The authors are with the University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia, E-mails: aleksandar.atanaskovic@elfak.ni.ac.rs, biljana.stosic@elfak.ni.ac.rs, natasa.males.ilic@elfak.ni.ac.rs

USRP front panel is shown in Fig. 1. The NI USRP connected to a host PC acts as a software-defined radio. Simplified overview of a SDR setup built around a NI USRP is depicted in Fig. 2 [2].

III. LABVIEW INTRODUCTION

LabVIEW [1-2] is developed by Jeff Kodosky of NI Cooperation in the mid year of 1986. Among other advantages, the three reasons listed below are the most important ones for applying LabVIEW: - LabVIEW is a powerful, platform-independent, graphical programming development system which is ideally suited for data acquisition, storage, analysis, and presentation; - LabVIEW is a programming environment which is widely used for measurement and automation; - LabVIEW helps to blend existing educational hardware inventory with virtual instrumentation in an economical way and with reasonable funds.

LabVIEW is used to teach digital signal processing. The graphical programming approach is based on data flow theory which is an ideal platform for learning how signals flow from one function to another such as from an acquisition function through a filter to a spectrum analysis and finally to a graph. Each function is an icon that is wired to other icons. The wires are the signals flowing from one icon to the next.

The basic building block of LabVIEW is the virtual instrument (VI). Conceptually, a VI is analogous to a procedure or function in conventional programming languages. Each VI consists of a block diagram and a front panel. The block diagram describes the functionality of the VI, while the front panel is a top level interface to the VI.

The NI LabVIEW Digital Filter Design Toolkit (DFDT) is complete filter design and analysis software that one can use to design filters to meet required specifications. With the DFDT, users work within the LabVIEW development environment to design, analyze, and implement a variety of IIR and FIR filters. This work has a number of advantages, such as the ability to do filter testing with simulated signals (generated algorithmically) or live signals. One can view the time waveforms or the spectra of both the input signal and the filtered output signal to show how the current design performs on real-world signals.

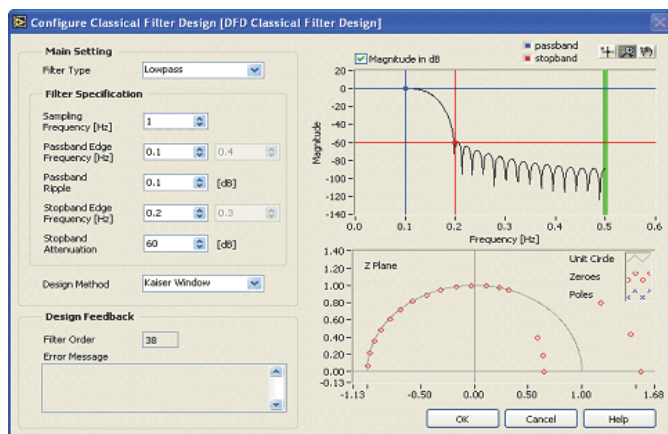


Fig. 3. The Classical Design Express VI of DFDT

Fig. 3 presents a classical design express VI of DFDT which allows users to specify filters by typing in passband/stopband frequencies and other parameters. Results of performed design are shown immediately as magnitude response and pole-zero plots.

IV. DIGITAL FILTER EXAMPLES

In order to present concept of digital filtering for the purpose of a computer based tutoring/learning system that uses LabVIEW and USRP, a system consisting of a transmitting and receiving parts has been realized. For correct operation of the system, it is necessary to properly set-up the USRP parameters (device name, carrier frequency, IQ rate, gain, active antenna) for both the transmitting and the receiving part. The transmitter is used to generate a multitone signal; one has to set the start frequency, the frequency spacing between the tones and the number of tones. The signal is transmitted as AM (Amplitude Modulation) signal with a carrier frequency corresponding to the carrier frequency of the USRP. In the receiving part, AM signal demodulation is performed in order to obtain original multitone signal generated in the transmitter, and then digital filter is used to observe filter's influence on the signal. One can select lowpass, highpass, bandpass or bandstop filter with Chebyshev or Butterworth approximation. The filter order as well as the cut-off frequency can be adjusted. In the receiving part, signal can be viewed in time and frequency domains. In order to observe the effect of signal filtering in time domain, it is recommended to use multitone signal generated with a lower number of tones. To observe the effect of filtering in frequency domain, signal with a higher number of tones with close frequencies can be used. In that case, a study of filter transfer function can be done.

This system can serve as an excellent complement to classroom teaching and learning. One can apply different filter types to test different input signals. A set-up presented here uses a signal composed of three sinusoidal components (such as one generated of three tones with frequencies 1000 Hz, 2000 Hz and 3000 Hz), as shown in Fig. 4.



Fig. 4. Front panel of transmitter (Signal generated with three tones on 1000 Hz, 2000 Hz and 3000 Hz)

The data passes through the currently designed filter, and analysis such as plots of the input and output waveforms and spectra can be generated further.

To interactively specify the desired filter, the parameters can be entered directly on user interface on receiver. The design method is set to Chebyshev approximation. Once the filter is designed, several alternatives for testing the design are possible. One can now select different filter types and get an immediate feel of the power spectrum of the signal at the receiver point, as well as the influence of the filter cut-off frequencies. Figs. 5-10 show graphs of the results of such analysis, i.e. the action of the filter on a test signal. In these cases, filter type is changed and cut-off frequencies are interactively varied for selected filter type.

Figs. 11 and 12 show block diagrams of the receiver and transmitter behind the VI [8].

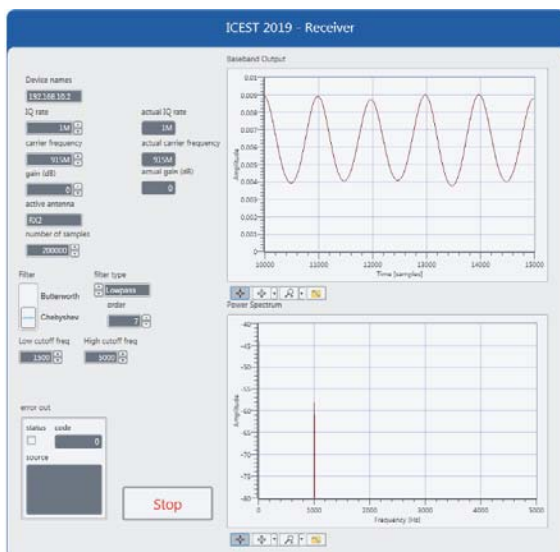


Fig. 5. Front panel of receiver for case of lowpass Chebyshev filter with 1500 Hz cut-off frequency

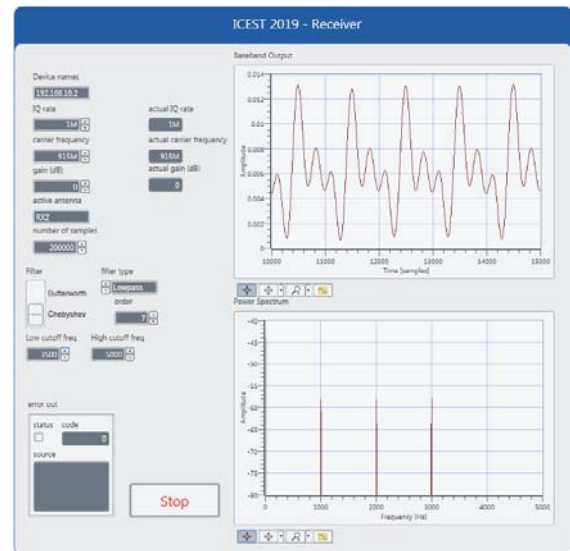


Fig. 7. Front panel of receiver for case of lowpass Chebyshev filter with 3500 Hz cut-off frequency

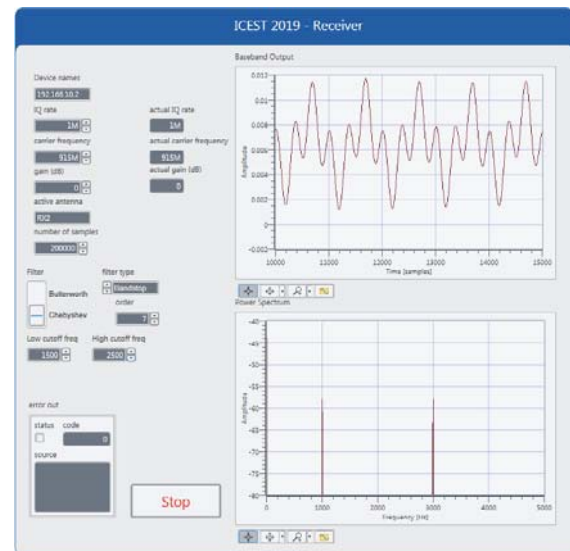


Fig. 8. Front panel of receiver for case of bandstop Chebyshev filter with 1500 Hz and 2500 Hz cut-off frequencies

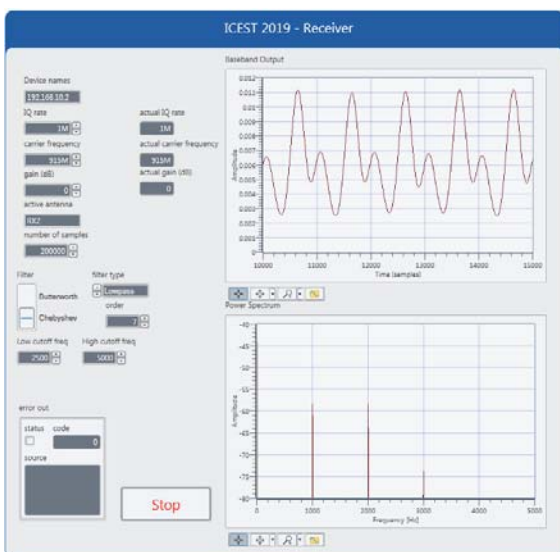


Fig. 6. Front panel of receiver for case of lowpass Chebyshev filter with 2500 Hz cut-off frequency

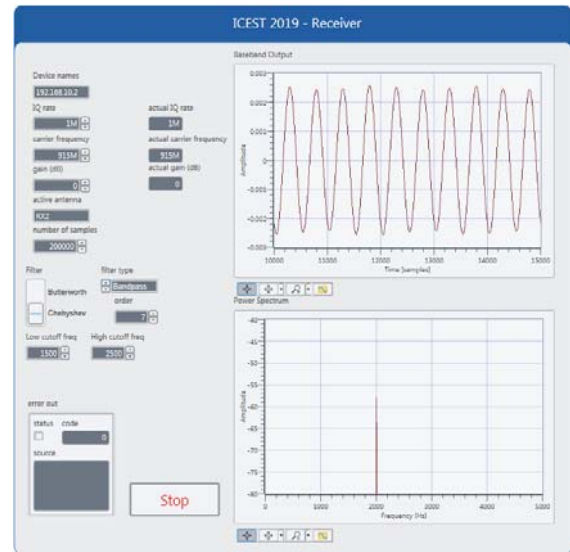


Fig. 9. Front panel of receiver for case of bandpass Chebyshev filter with 1500 Hz and 2500 Hz cut-off frequencies



Fig. 10. Front panel of receiver for case of highpass Chebyshev filter with 1500 Hz cut-off frequency

V. CONCLUSION

One of the major requirements in engineering education is to provide students with convenient environments to practice what they have been taught or what they have learned conceptually.

In this article, it is presented how the LabVIEW and USRP can be used to give students hands-on experiences and teach them how to link theory with practical implementation instead of only using theoretical analysis and simulations. Additionally, it is important to teach students the importance of testing their VIs as they are building their systems instead

of building the whole system and then finding that it does not work and is very difficult to debug.

The educational benefits, i.e. learning outcomes of this application are the following: design and implementation of digital filters and understanding VI concepts.

ACKNOWLEDGEMENT

This work has been partially supported by the Ministry for Education, Science and Technological Development of Serbia through Grant # TR32052.

REFERENCES

- [1] National Instruments, *LabVIEW Digital Filter Design Toolkit User Manual*, February 2005.
- [2] National Instruments, *Une introduction à la radio définie par logiciel avec NI LabVIEW et NI USRP*, Version 1.1 – Q4 2013.
- [3] N. Kehtarnavay and N. Kim, *Digital Signal Processing System-Level Design Using LabVIEW*, Elsevier, 2005.
- [4] S.K. Mitra and J. Kaiser, *Handbook for Digital Signal Processing*, 1993 John Wiley and Sons, Inc.
- [5] A. Abrol and E. Hamke, "Introduction to Communication Systems Using National Instruments Universal Software Radio Peripheral - Lab Manual", The University of New Mexico, September 11, 2014.
- [6] T.B. Welch and S. Shearman, "AC 2011-2086: LabVIEW, the USRP, and their Implications on Software Defined Radio", American Society for Engineering Education, 2011.
- [7] T.B. Welch and S. Shearman, "Teaching Software Defined Radio Using the USRP and LabVIEW", 2012 IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), 25-30 March 2012, pp. 2789-2792.
- [8] B.A. Black, "Introduction to Communication Systems - Lab Based Learning with NI USRP and LabVIEW Communications - Student Lab Manual", National Instruments, 2014.

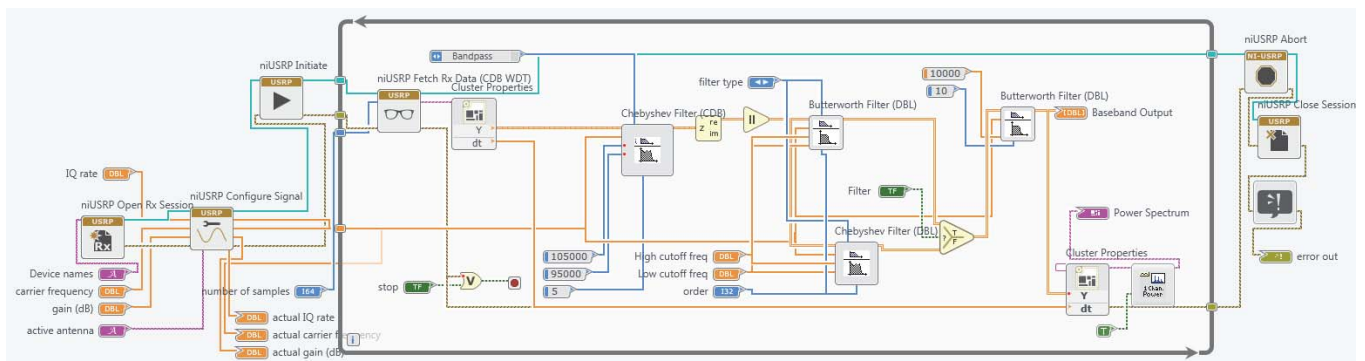


Fig. 11. LabVIEW VI interface of receiver - block diagram of the system behind the VI

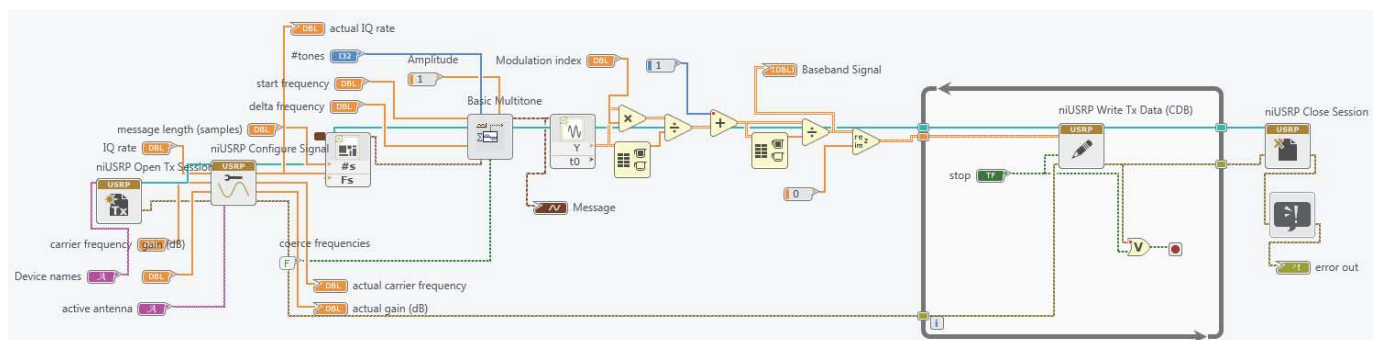


Fig. 12. LabVIEW VI interface of transmitter - block diagram of the system behind the VI