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Design and Development of an Interactive Analog and Digital Filters Characterization Laboratory Based on LabVIEW

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ABSTRACT

Remote labs, also known as iLabs are increasingly being preferred over the conventional physical labs to enhance learning in engineering disciplines. They allow the simultaneous sharing of expensive laboratory equipments between students and universities online. In this research, an iLab that characterises analog and digital filters was designed on the LabVIEW platform. It covers; filtering concepts of both analog and digital filters as well as stability of filters. Low-pass, high-pass, band-pass, and band stop analog filter circuits were designed using Multism Circuit Design Suite V13.0, then implemented on the NI ELVIS II prototyping board powered by LabVIEW software using LM 741 Op-Amps, relay circuits for switching between different outputs for analog filters, capacitors, and resistors. The NI ELVISmx Digital Write express Virtual Instrument was used to control the relays connected at different output pins of the analog filters and to remotely switch between the filter types over the local network. The NI ELVISmx Analog Write express Virtual Instrument was used to read analog signals from the output pins of the filter circuits into the user interface. Digital FIR and IIR filters were designed and developed using the LabVIEW 2013 software package together with the LabVIEW Digital Signal Processing module. An intuitive user interface was designed to provide the means for launching, monitoring, controlling, and reading results from the laboratory hardware equipment and the digital filters. A learner can access the lab through a web link which runs on the iLabs Shared Architecture, select an experiment of interest, gain control of the laboratory hardware equipment, set experiment parameters and obtains results in real time.

Keywords: Analog filters, Digital filters, Signal Processing.

1.0 INTRODUCTION

1.1 Background

Innovations in the field of experimentation in engineering have greatly changed methods of delivering knowledge to learners. Pedagogical techniques are changing from the traditional “chalk and talk” sessions to “application-orientation” or “workshop/laboratory-based” approaches so as to reinforce theoretical concepts [1]. Some of these approaches have been designed to provide students and researchers with experimentation experience remotely over the internet.

In many higher institutions of learning like Makerere University, the number of students admitted to Engineering disciplines has greatly increased in the recent past years but the resources (equipments and laboratory technicians, financial resources and space) to adequately train them using the conventional workshop/Laboratory based approaches have not increased proportionately. However technological advancements in education have opened doors to Remote Engineering in Education [2].

Sophisticated technologies such as the iLabs Shared Architecture (ISA), National Instruments Laboratory Virtual Engineering Workbench (NI LabVIEW) Software Package, and National Instruments Engineering Laboratory Virtual Instrument Suite (NI ELVIS II) Prototyping Board enable remote access to laboratory equipment. This allows institutions to gain leverage on the few very expensive equipment available so as to reinforce theoretical concepts delivered in lectures.

1.1.1 Digital Signal Processing

It is difficult to connect Mathematical concepts in Digital Signal Processing (DSP) and Network theory with their practical engineering applications. However many "recipes" suggest "visualization" of DSP theory [3]. LabVIEW software package provides a standardized simpler way of visualizing DSP and Network theory concepts.

LabVIEW provides a graphical development environment with built-in functionality for simulation, data acquisition, instrumentation, measurement analysis, and data presentation. The User Interface (UI) is created by "drag-and-drop" of pre-defined objects [4]. LabVIEW Graphical applications which are known as Virtual Instruments (VIs), "mimic" real measurement and control instruments such as oscilloscopes, voltmeters, ammeters, functional generators, Bode analyser, DMM (Digital Multi-meter) etc. [5]. These VIs are used to exploit the potentials of hardware platforms to the full extent.

LabVIEW standard filter palettes possess a range of tools for synthesis and analysis of filters. Instead of the expensive and bulky lab equipments in DSP Labs, it is more appropriate to use NI LabVIEW software package in combination with NI-ELVIS II+ hardware developing platform and a personal computer.

1.1.2 Designing of Digital and Analog Filters

Two types of digital filters were considered, namely IIR and FIR. The design of IIR filters is closely related to the design of analog filters. An analog filter is normally designed and a transformation carried in the digital domain using either impulse invariant transformation or bilinear transformation. In this research, the focus was placed on designing minimum order IIR filters to meet a set of specifications using LabVIEW function with each design accompanied by a plot of its frequency response, impulse response and pole-zero diagrams [8].

The design procedure of analog filters has two distinct stages. In the first stage, a frequency response function H (jw) was derived to meet a set of specifications. In the second stage, an electronic circuit was designed to generate the frequency response function. Filter circuits can be constructed entirely from passive components or can contain active components such as operational amplifiers [7]. The transmission of data from the NI-ELVIS 11 board platform to the computer and vice versa was carried out over the USB media.

1.2 Problem

With the rapid advancement in software and hardware developments in DSP especially in the areas of audio, image and video processing, it is vital for students to complement their theoretical learning with practical applications. At Makerere University, School of Engineering, the BSc. Electrical, BSc. Telecommunications, and BSc. Computer Engineering curricula contain courses in analog signal processing and digital signal processing.
However, these courses are taught theoretically during lectures. The DSP course is taught in the fourth year of study to all programs in the Department of Electrical and Computer Engineering. There are no practical sessions held to supplement the theory learnt during normal lecture time. Therefore, students do not get ample time to explore and understand DSP concepts practically and to understand the trade-offs between analog and digital filters. Moreover, the laboratory resources available do not provide a comprehensive experience to explore the practical study of DSP.

Also, in the Electronics laboratory, there are only four pieces of CK342K boards which, when compared to the increasing numbers of students, cannot be enough for individual practical exploration of the study.

Although the iLabs platform has been modified to expand its functionality to include experiments in DSP to supplement the conventional laboratories, these experiments do not provide practical hands-on experience.

1.3 Objectives

The main objective of this project was to design and implement an interactive analog and digital filters laboratory for deployment on the ISA to supplement the existing conventional laboratories. The specific objectives were;

1. To design analog and digital filters (high-pass, low-pass, band-pass and band-stop) operation and the trade-offs between them.
2. To explore the use of LabVIEW virtual interactive DSP experiments and hardware DSP laboratory tools on the NI-ELVIS II + development platform to design digital signal processing experiments.
3. To demonstrate concepts of sampling, under sampling, aliasing, anti-aliasing filter, and windowing as applied to DSP.
4. To determine the stability, zeros and poles for different digital filter topologies.

2.0 METHODOLOGY

2.1 Design tools and Requirements Specification.

The methods, tools and processes employed in the design and development of this project included; designing of analog filters circuits, designing of digital filters (IIR and FIR) using DSP LabVIEW toolkits, designing of express VIs to illustrate DSP concepts of sampling using DSP LabVIEW toolkits, aliasing, Digital to Analog Converter (DAC) and Analog to Digital Converter (ADC), designing of a LabVIEW search engine connected to Google, and designing of a remote panel connection to the lab. Using passive and active components to design Analog circuits, relay switches to toggle between different filters together with the NI-ELVIS 11 prototyping board. The design process involved requirements specification as shown in Table 1 below.

Table 1: Requirement Specification for Analog and Digital Filters

No 1	Hardware for Analog Filters	Component specification
1	OPAMP (6)	LM741

2	Resistors (watt)	1.2kΩ (4), 10kΩ (4), 1kΩ (2)
3	Electrolytic Capacitors	1µf (4), 10nf(4)
4	Jumper wires	4 packs each consisting 50 jumper wires
5	NI ELVIS 11 Board (2)	Consists of a function generator, Oscilloscope, digital multi-meter, DC power supply(±15V, 5V, GND), Bode analyzer, Digital I/O
6	Contact Relay (4 of them)	SRD-05VDC-SL-C
7	Transistor (4 of them)	TIP122
No 2	**Software**	**Purpose**
1	Multisim 13.0	Simulation
2	LabVIEW 2013 with DSP toolkit (For digital filters)	Signal acquisition and representation

2.2 Technology Description

2.2.1 Analog Filters

The design of analog involves signal acquisition, signal filtering, signal representation and analysis. With LabVIEW 2013 launched, the NI bode analyser express VI is accessed to be used to acquire signals from the NI ELVIS 11 BOARD.

2.2.2 Signal Acquisition

On the LabVIEW 2103 Block diagram, NI ELVIS Bode analyser is used to measure the gain and phase shift versus frequency for passive and active linear circuits of the acquired signal from the NI ELVIS board.

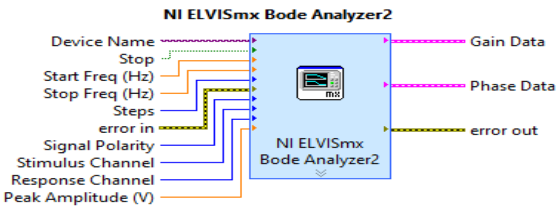

Figure 1: NI ELVISmx Bode Analyser

2.2.3 Digital Filters

The main digital filters, FIR and IIR were designed. The design of digital filters involves signal acquisition, representation and analysis. Using the LabVIEW DSP MODULE the following express VIS were used for filtering and signal representation: Function Generator, NI AAI Base.lvlib: Equi-Ripple LowPass.vi, NI_AAI Base.lvlib: Equi-Ripple HighPass.vi, Data Acquisition Unit (DAQ) Assistant.

2.3 Designing of Analog filters

2.3.1 Analog Filter circuit design

Using Multisim 13.0 software, simulations of analog (Low-pass, High-pass and Band-pass) filters were of performed using the ideal LM741 Op-Amps, Capacitors, Resistors and power supplies. The aims of these simulations were;

1. To obtain the theoretical gain and phase graphs of the filters
2. To obtain the cut off frequency
3. To build confidence in constructing analogue circuits.

2.3.2 High-pass filter design

It was implemented using the LM741 Op-Amp, two 1µF capacitors and two 1.2kΩ resistors. Excitation of the filter was provided by the LabVIEW function generator. *Figure 2* shows a simulated circuit diagram of the HP filter with a cut-off frequency of about 132.6 Hz, and the gain and phase bode plots obtained from the physical circuit using the NI ELVISmx Instrument Launcher Bode Analyzer.

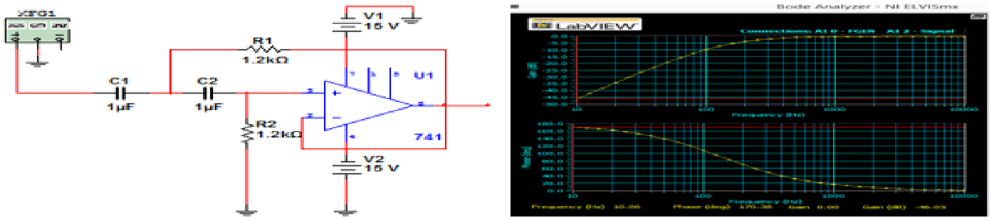

Figure 2: HP Multisim circuit, Gain and phase bode plots

2.3.3 Low-pass Filter Design

It was implemented using the LM741 operational amplifier, two 1kΩ resistors and two 10nF capacitors. Excitation of the filter is provided by the LabVIEW function generator. The low pass filter has a cut off frequency is Hz F_c = 1591.5 Hz

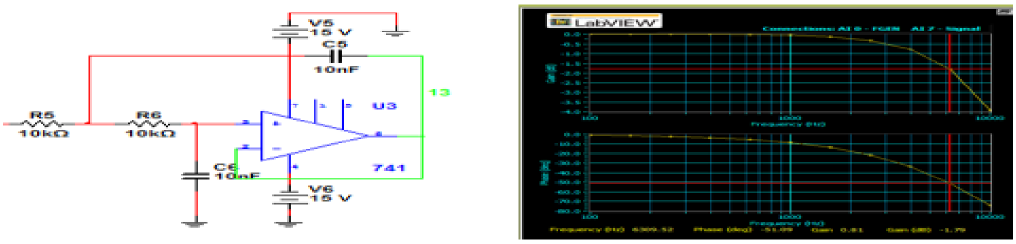

Figure 3: LP Multisim circuit. Gain and bode plots

2.3.4 Band-pass Filter Design

It was designed as a cascade connection of a HP and LP filters. It consists of three levels; HP filter, amplifier of gain A = 11, and LP filter. Each level contains an LM741 Op-Amp resistors and capacitors.

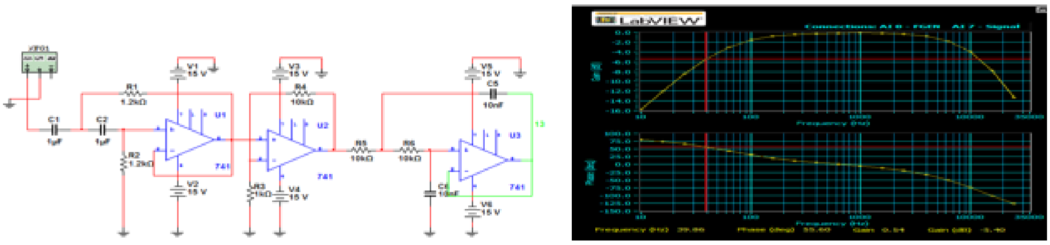

Figure 4: BP circuit, Gain and Phase bode plots

2.3.5 Low-pass, High-pass and Band-pass Filters inter-connected with relay circuit

A relay circuit was built to enable a remote user who is interfacing with the lab to be able to switch between different filters types. *Figure 5* below shows the combined circuit. The circuit board is then connected to a computer through USB type B. With LabVIEW 2013 launched, the NI bode analyser express VI is used to acquire signals from the NI ELVIS 11 board.

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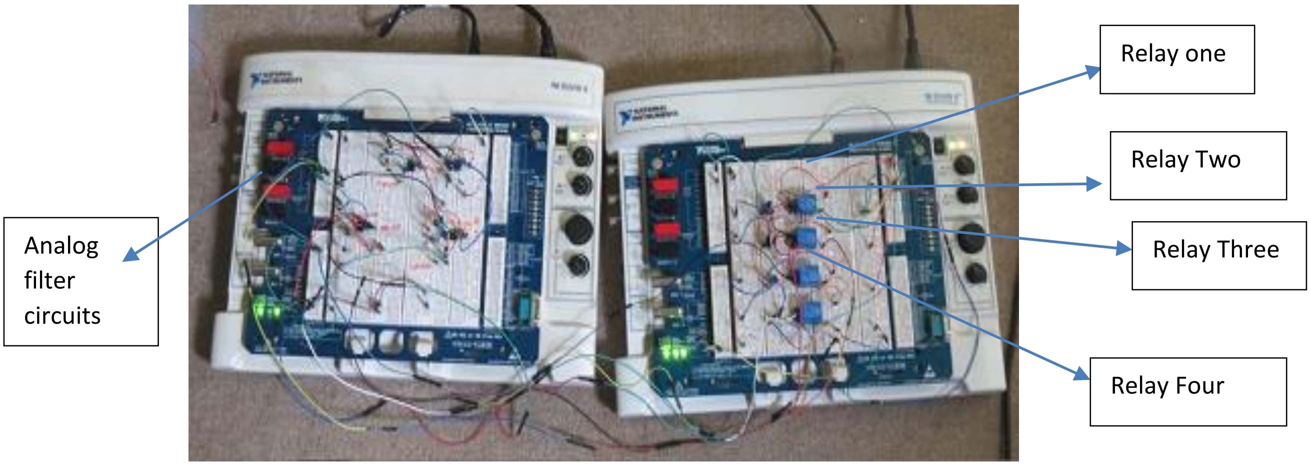

Figure 5: Low pass, High Pass and Cascaded Band Pass Filter

3.0 DISCUSSION OF RESULTS

3.1 Results of Analog Filters

3.1.1 Low-pass Analog Filter GUI

When RELAY ONE is closed, keeping the other relays open, a LED lights green showing that relay one has been activated to in order to bias the Low-pass filter. For an input sinusoid waveform of amplitude 2V, the output waveform picked from Pin 6 of the LM741 Op -Amp has an amplitude of 0.1 as shown in *Figure 6*. The Low-pass filter passes signals whose frequency is lower than its cut-off frequency $f_c = 1591.5\ Hz$ without significant attenuation while signals with frequencies higher than the cut-off one are attenuated.

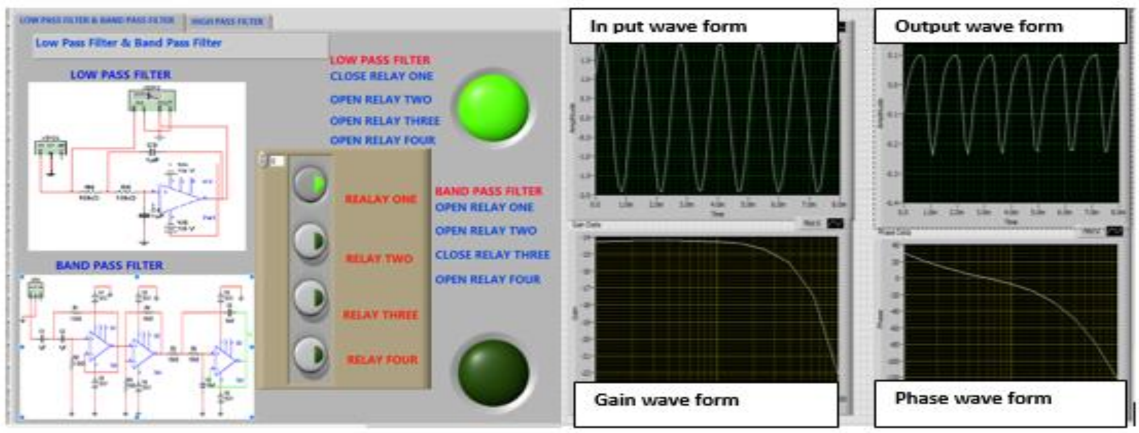

Figure 6: Wave form graphs for LP filter

3.1.2 High pass filter GUI

When RELAY FOUR is closed keeping RELAY ONE, RELAY TWO AND RELAY THREE open, a LED lights green showing that RELAY FOUR has been activated in order to bias the High-pass filter. As shown in *Figure 7*, the High-pass filter passes signals whose frequency is lower than its cut off frequency 136.2Hz with insignificant attenuation while signals with frequencies higher than the cut-off are passed without attenuation.

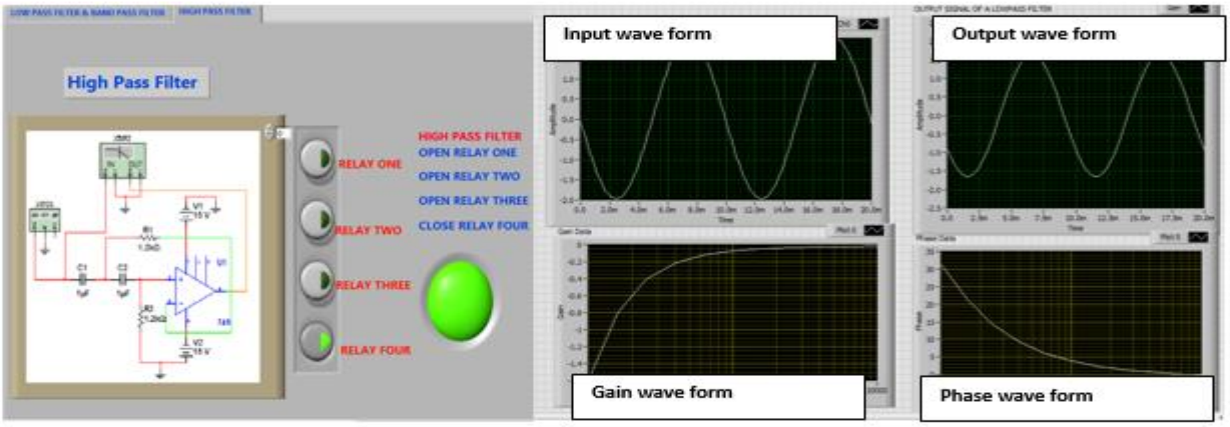

Figure 7: GUI for the High pass filter with relay circuit configurations

3.2 Bandpass analog filter GUI

Closing RELAY THREE and keeping the rest of the relays open, a LED lights green showing that RELAY THREE has been activated in order to bias the High-pass filter. Using the Bode analyser as shown in the gain and phase waveform from Ni ELVISmx palette of virtual instruments, for a band-pass filter with a lower and upper cut off frequencies at 70Hz and 1000Hz, only frequencies in this range are passed. All frequencies outside this range are attenuated as shown in gain and phase waveforms in *Figure 8*.

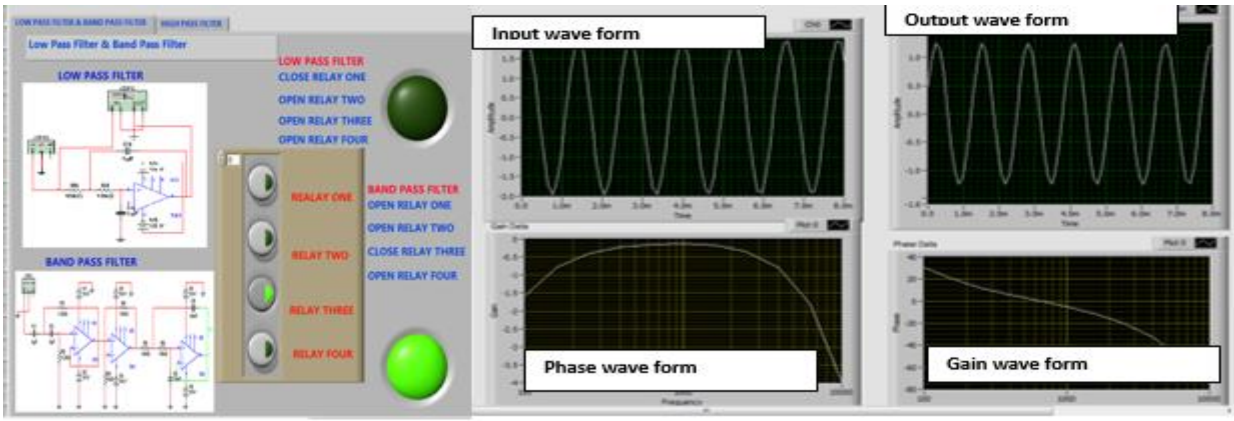

Figure 8: GUI for Band pass filter with wave forms

3.3 Design process and results of Digital Filters

LabVIEW DSP Module and LabVIEW 2013 software were used to design and display results of digital filters. The main digital filters of FIR (High-pass, Low-pass, Band-pass and Band-stop filters), IIR (Butterworth, Chebyshev, Inverse Chebyshev, Elliptic, Bessel) were designed.

3.3.1 FIR filters, a Low-pass filter and band-pass filter

The acquired signal or simulated Gaussian white noise from the computer sound card is filtered with either low pass or band pass filter and results displayed and analysed the LabVIEW user interface as shown in *Figure 9*. *For example, for the FIR* windowed topology having 50 taps, Lower pass band = 1200Hz, Upper pass band = 3000Hz, Lower stop band = 500Hz, Upper stop band = 3500Hz, Scale = 12.85 and 100 samples, the Gaussian white noise wave form obtained from the computer sound card and the output filtered wave form for a Low-pass and Band-pass FIR filters were displayed as in *Figure 9*.

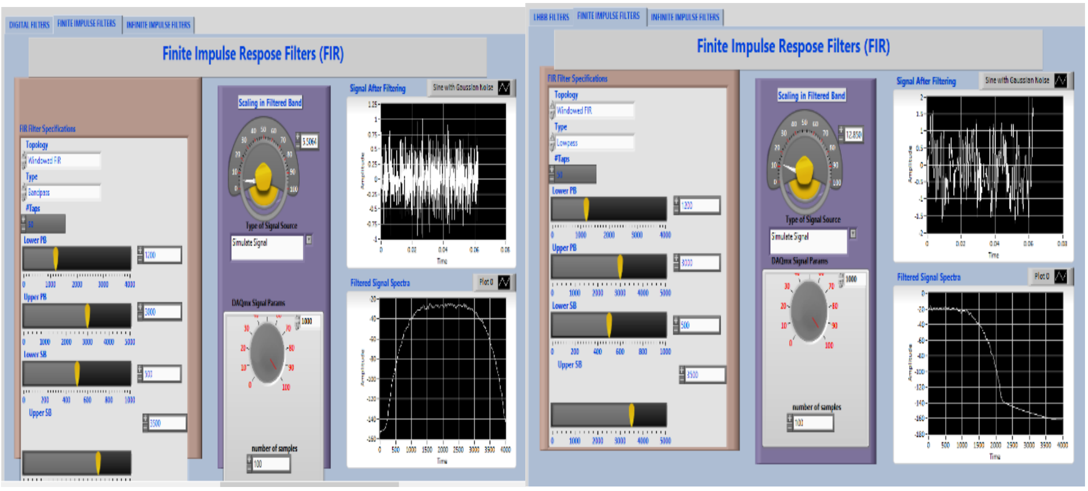

Figure 9: Low pass and Band-pass FIR filter

3.3.2 IIR filters Digital Filter Topologies.

Figure 10 shows the magnitude response and the pole-zero plot of an inverse Chebyshev lowpass filter with the filter parameters set as follows: Cutoff frequency = 500 Hz, Stop frequency = 1000 Hz, Passband attenuation = 15 dB, Stopband attenuation=100dB, Sampling rate = 10951 Hz, Order = 10. If the order of the filter is increased while keeping the other specifications constant, the magnitude response plot slope becomes steeper.

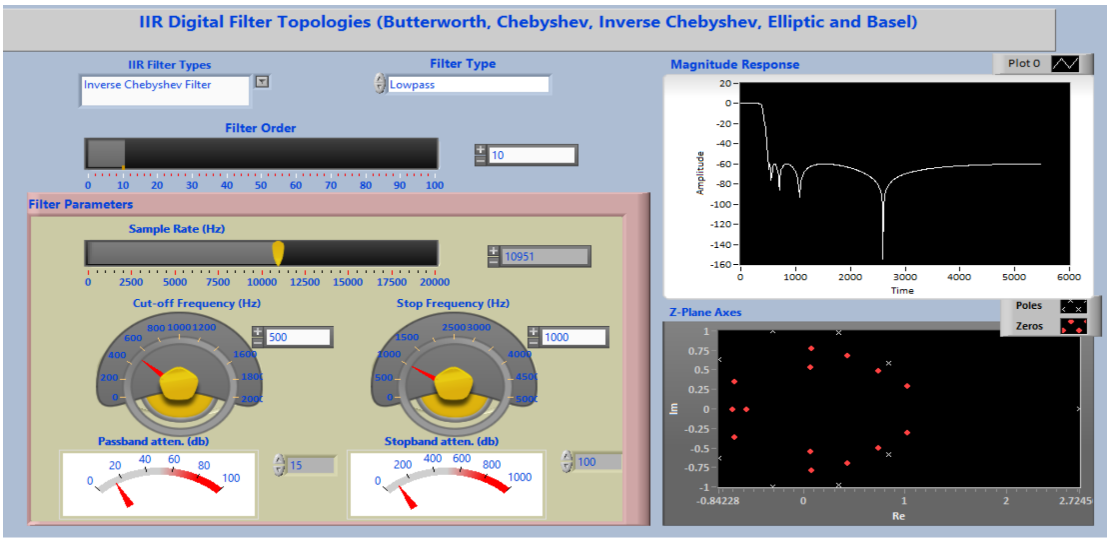

Figure 10: UI showing Magnitude response and Pole-Zero Plot of a 10th Order Inverse Chebyshev Filter

Results for Butterworth, Chebyshev, Elliptic and Basel filters are obtained in a similar way by selecting the filter of interest from the user interface shown in Figure 10.

3.3.3 Aliasing, Sampling, Quantization, and Signal Reconstruction

The original signal and the reconstructed were displayed on the same graph as shown in *Figure 11* below. The Discrete waveform, Digital waveform, Analog frequency, Digital frequency and the Number of samples skipped are also displayed on the user interface enabling the experimenter to examine proper signal sampling and reconstruction.

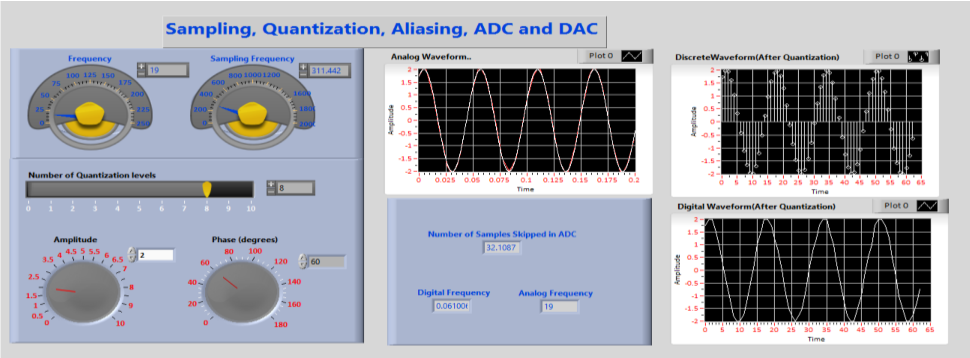

Figure 11: User Interface for Aliasing, Sampling, Quantization, or Signal Reconstruction

From digital and analog filters explored above, the frequency response of digital filters indicated better roll-off and stopband attenuation than for analog filters. Analog filters have ripples in the passband. Any amount of flatness achievable with analog filters is limited by the accuracy of their resistors and capacitors. On the other hand, digital filters are nearly perfectly flat. For Analog filters, a theoretical result has it that Chebyshev Type I have a response lower than that of Butterworth filters. Practical results however indicated that the shaping factor of a Chebyshev type I is less than that of a Butterworth.

4.0 LIMITATIONS AND POLICY IMPLICATIONS

4.1 Limitations of the study

During designing of analog filters, it was difficult to identify proper criterion for selecting ICs, resistors and capacitors with low noise, response time and harmonic distortion. This is because analog electronics are generally nonlinear. The distortion and electronic noise due to the passive components especially resistors and the input filtering capacitors, proved difficult to greatly minimize. On the other hand, digital filters took a tremendous amount of time to design and develop.

4.2 Policy implications

A recent survey of engineering training institutions in Uganda by the Engineers Registration Board (ERB) in 2018 revealed that, many universities and technical institutions offering engineering programmes especially in electrical, computer and telecom engineering are understaffed and inadequately equipped due to limited financial resources. This online laboratory and many others developed under iLabs@MAK would provide opportunity to financially constrained institutions to share very expensive laboratory equipments cheaply.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Analog and digital filters are very important in signal processing. Whereas analog filters are implemented using hardware, digital filters are implemented using software. For analog filters, the use of an LM741 operational amplifier greatly simplified their implementations as low-pass, high-pass, band-pass and band-stop.

The windowing method was used to design digital FIR filters because of its simplicity. Moreover, LabVIEW provides in-built FIR functions such as the Hamming window, Gaussian window and Kaiser Window which further simplified the design process. A combination of the NI ELVISmx virtual instrument and LabVIEW user interface made it possible to remotely control and monitor the behaviour and nature of waveforms for different configurations of both the analog and digital filters. The laboratory also enables exploration of the DSP concepts of sampling, under sampling, aliasing, anti-aliasing filter, and windowing.

5.2 Recommendations

The input filtering capacitors can be precisely specified so as to minimize nonlinearity in analog filters. For digital filters, oversampling a signal at twice Nyquist rate can be used to relax the filter roll-off. For practical applications however, the selection of which filters to use requires identification of whether the application requires a Linear phase response or not, ripples and narrow transition band. Further research should be carried out on how to make the students' experience as close as possible to a physical laboratory experience.

5.3 Acknowledgement for funders

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