Design of a Low Cost PC Based Digital Storage Oscilloscope Using Virtual Instrumentation

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***Abstract*—Instrumentation for the purpose of precise and accurate measurements and data acquisition is the spine of all engineering domains. However, traditional measuring instruments lack flexibility and scope for modifications, have greater costs, larger sizes and require more maintenance as well. Thus, virtual instrumentation with minimal hardware setup is the current need of the engineering industry. This project was particularly focused on virtualization of a Digital Storage Oscilloscope, one of the most crucial and widely used electronic test equipment and measurement instrument. A PC-based digital storage oscilloscope was designed using NI LabVIEW and a compatible hardware interfacing unit was developed using Arduino Nano, an ATmega328 based development board. Keysight InfiniiVision DSO-X 2002A, a commercially available DSO was used as a function generator and the performance analysis of the virtual oscilloscope was compared against the same standard. Six different signals, viz. DC, pulse, square, triangle, ramp and sine were considered in order to analyze the comparative results acquired from the standard and the virtual DSOs respectively. Results confirmed optimum performance of the designed virtual oscilloscope and assured its potential applications in the field of electronic measurements and instrumentation.**

***Index Terms*— Measurements, Oscilloscope, Signal Analysis, Virtual Instrumentation**

I. INTRODUCTION

OSCILLOSCOPE is an electronic measurement instrument that displays voltage signals with respect to time. In effect, it plots the instantaneous voltage values of the signal as a function of time. Conventional oscilloscopes used cathode ray tubes (CRTs) to display the waveforms and were known as cathode ray oscilloscopes (CROs). CROs are still used today by hobbyists to analyze continuous analog signals. However, the digital storage oscilloscopes (DSOs) have revolutionized the process of signal analysis. DSOs have an analog-to-digital converter (ADC), which converts the continuous analog signal into discrete samples of digital data with the bandwidth not exceeding half the sampling rate of the ADC, known as Nyquist limit [1]. This data is then processed using digital signal processors and displayed on an LCD or LED screen. DSOs can also save the signal data in various formats for subsequent analysis or documentation. Furthermore, DSOs can analyze multiple parameters of a signal at once and can also display overlays and annotations representing the same, which is a key factor responsible for their world-wide fame.

Virtual instrumentation is the notion of designing fully functional instruments virtually, on a software level with very minimal or absolutely no hardware components. A virtual instrument (VI) principally constitutes of a PC with the VI application and driver softwares installed, and a hardware interfacing unit in order to interface them with the physical world. A virtual instrument generally resembles the actual instrument in terms of visual appearance and can be operated using a graphical user interface (GUI).

The greatest advantage of virtual instruments is that, being software applications, they can be upgraded without much issues. Moreover, they cut down the cost of the actual hardware instruments and also the resources used for producing them. Furthermore, multiple virtual instruments can be installed on a single PC and be used as and when required, rather than carrying heavy instruments everywhere. All in all, virtual instruments are modular, cost-effective and extremely convenient.

Virtual instrumentation is an emerging technology and some of the previous works in this field have addressed the same problem statement. However, each approach, including ours, is unique in terms of the hardware and software utilization for realizing the design and the overall functionality of the developed instrument. K.P.S. Rana *et al.* [2] developed a mixed signal virtual oscilloscope using NI LabVIEW and a DAQ card. They pointed out the problem of DSOs to not effectively process frequency-varying time signals and stated that mixed signal oscilloscopes (MSOs) used for this purpose are very costly; virtual instrumentation helped them achieve the goal of cost reduction. Ping Gong *et al.* [3] developed a virtual oscilloscope using NI LabVIEW and NI USB data acquisition card. They also discussed the time-domain analysis and frequency-domain analysis of the signals processed using their virtual oscilloscope. Norizam Sulaiman *et al.* [4] designed a PC-based 4-channel DSO using digital signal processing (DSP) techniques. They used peripheral interface controller (PIC) as the interfacing device and developed the software using Microsoft Visual C++. Wei Jiang *et al.* [5] designed an oscilloscope using virtual instrumentation technique. They used LabVIEW for designing the virtual instrument and utilized PCI-6024 data acquisition card as the interfacing device. Chandan Bhunia *et al.* [6] developed a PC-based virtual oscilloscope by designing a parallel port data acquisition device and a software package for displaying acquired signal. They also suggested the use of this low-cost oscilloscope for undergraduate laboratory demonstration and instruction purposes.

II. SYSTEM DESIGN

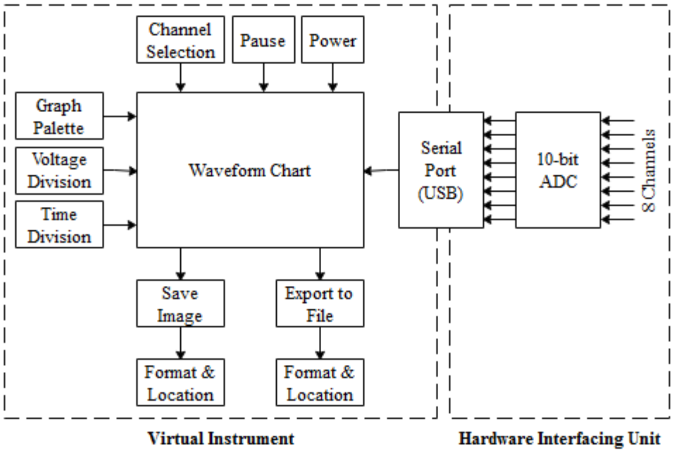


Fig. 1. Block diagram of the proposed system

The overall design of the proposed system (Fig. 1) can be divided into two sub-domains, viz. the virtual instrument and the hardware interfacing unit. The virtual instrument is a software package designed to mimic the actual instrument that it represents, while the hardware interfacing unit establishes a connection between the real and the virtual worlds.

A. Virtual Instrument

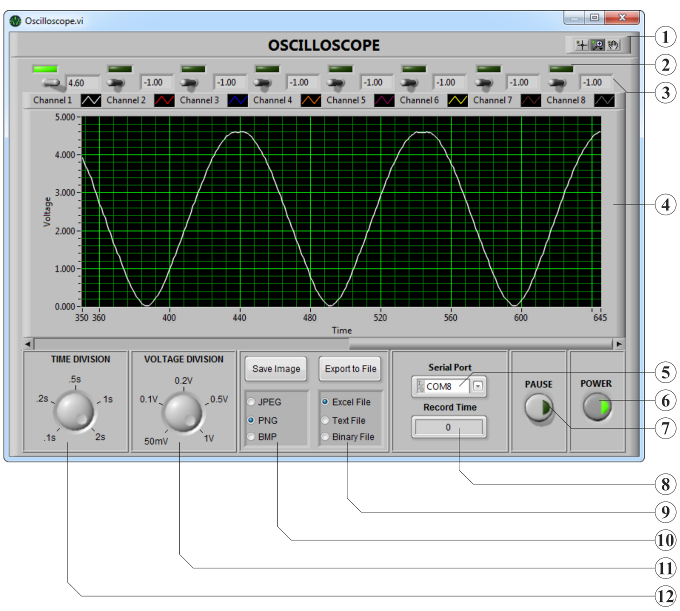


Fig. 2. Front panel (GUI) of the virtual instrument

Table 1. Description for Fig. 1

Label	Description
1	**Graph Palette** is used to move cursors, zoom and pan the graph.
2	**Indicator LED** indicates whether the channel is active or not.
3	**Channel Readout** displays the instantaneous voltage value.
4	**Waveform Chart** displays the real-time waveform.
5	**Serial Port** is used to select the COM Port for connection.
6	**Power Button** is used to switch the VI on or off.
7	**Pause Button** is used to pause the waveform.
8	**Record Time** is the time through which data has been exported.
9	**Export to File** is used to write data to a specified file format.
10	**Save Image** is used to export the instantaneous image of the VI.
11	**Voltage Division** is used to adjust the vertical divisions.
12	**Time Division** is used to adjust the horizontal divisions.

The virtual instrument was designed using NI LabVIEW and a standalone executable file of the virtual instrument was exported as a GUI application. Fig. 2 illustrates the GUI or what is called as the front panel of the virtual instrument and Table 1 holds the description of all the callouts represented in Fig. 2.

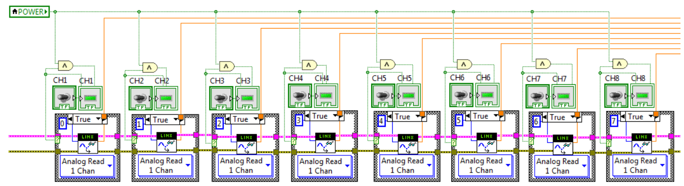


Fig. 3. Block diagram of data acquisition and channel controls

The channel controls (Fig. 3) allow the user to select between 8 different channels, even multiple at a time, and the status of each channel is indicated by the corresponding indicator LED on the front panel. This sub-system also takes care of data acquisition of the individual channels.

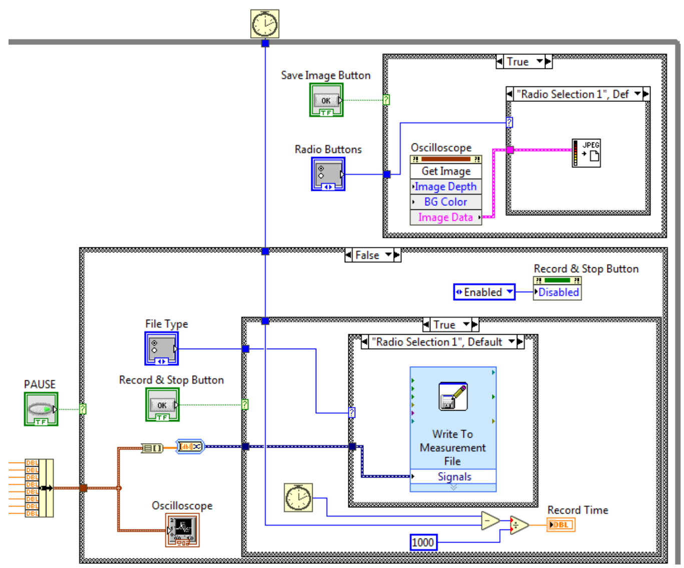


Fig. 4. Block diagram of waveform display and data storage controls

Fig. 4 illustrates the sub-system responsible for displaying the waveform and storing the data either as an image or as discrete values exported to a file. A waveform chart is used to graphically display the input signal with respect to time and the graph palette is used to move cursors, pan and zoom the display. The design supports consecutive viewing of signals from 8 channels at a time and the instantaneous voltage values of each channel are displayed next to their respective controls; if a channel is disabled, it's voltage value is regarded as -1.00.

The data storage feature is what differentiates this virtual instrument from regular virtual oscilloscopes to be regarded as a virtual DSO. The data storage controls allow the user to save the waveform data as an image (JPEG, PNG or BMP), which is mostly used for the purpose of documentation or export the discrete values to a file (XLSX, LVM or TDMS) for subsequent analysis using third-party softwares such as Microsoft Excel, MATLAB, etc. In the latter case, record time is displayed in order to indicate the time through which data has been exported.

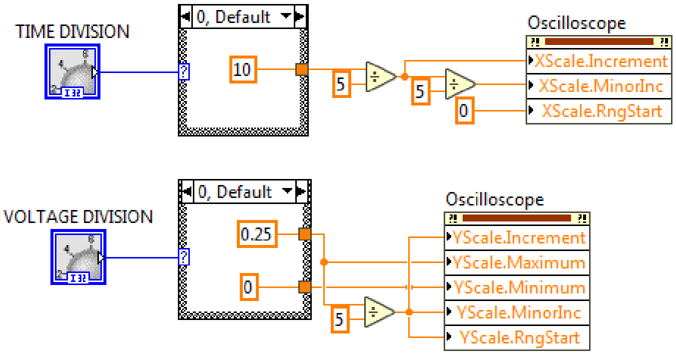
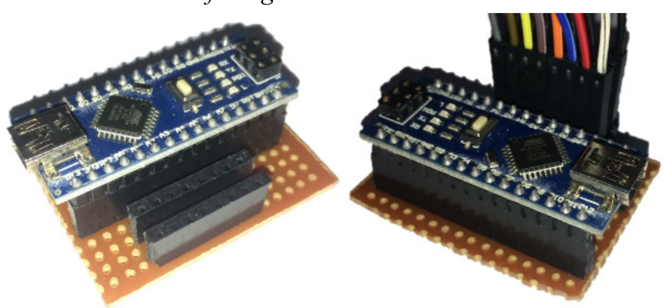


Fig. 5. Block diagram of time and voltage division controls

The time and voltage division controls (Fig. 5) are used to alter the X-axis (time) and Y-axis (voltage) scales respectively. Suitable scaling factors are provided so as to obtain the time divisions of 100 ms, 200 ms, 500 ms, 1 s and 2 s and voltage divisions of 50 mV, 100 mV, 200 mV, 500 mV and 1 V respectively.

B. Hardware Interfacing Unit



(a) **(b)**

Fig. 6. Hardware interfacing unit (a) without probes and (b) with probes

Since this project was focused on designing a cost-effective virtual DSO, the hardware interfacing unit was designed using Arduino Nano, a development board based on ATmega328. The analog inputs of Arduino were configured as 8 different channels and the built-in 10-bit ADC was used to digitize the input signals from (0-5) V to (0-1023) discrete values. The acquired data was transferred to the virtual instrument hosted on a PC using serial communication through the USB.

Fig. 6 (a) shows the hardware interfacing unit without any probes so as to clearly display the connections for 8 different channels; the top rail is for signal lines of individual channels and the lower one is the GND rail. On the contrary, Fig. 6 (b) shows the hardware interfacing unit with the probes attached. Probes of 8 different colors, viz. white, red, blue, orange, violet, yellow, brown and grey were used to indicate the respective channels and the same color convention was also followed while designing the front panel of the virtual instrument. All the GND probes are black in color.

Arduino Nano operates at clock frequency of 16 MHz and has its ADC set to 125 kHz, refer to (1). Since each conversion in AVR takes 13 ADC clock cycles, the maximum sampling rate was only about 10 kHz, refer to (2).

$$16\ MHz/128 = 125\ kHz \tag{1}$$

$$125\ kHz/13 = 9615\ Hz \approx 10\ kHz \tag{2}$$

III. EXPERIMENTATION

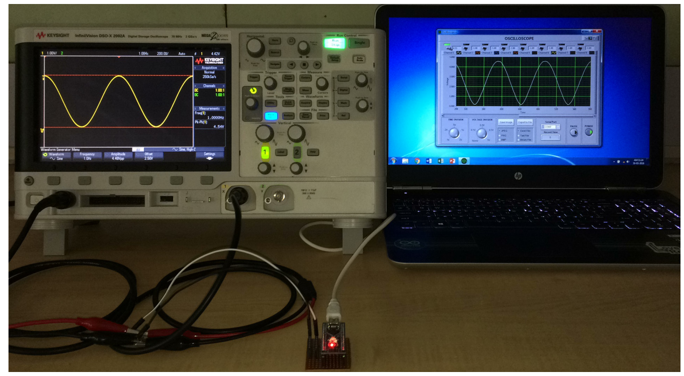


Fig. 7. Experimental setup

Fig. 7 shows the experimental setup used to analyze the performance of the proposed virtual DSO. The virtual DSO was fed with 6 different signals, viz. DC, pulse, square, triangle, ramp and sine, and its performance was analyzed based on its ability to accurately display these test signals.

Keysight InfiniiVision DSO-X 2002A [7], a standard DSO, was used as a function generator to generate the 6 standard test signals each of 5 V amplitude (TTL logic preset) and 1.00 Hz frequency (except DC signal), which were fed back to the same DSO for analyzing their actual parameters. The same signals were also fed to the virtual DSO through the hardware interfacing unit by tapping the connections. Comparative analysis was performed in order to verify the optimal behavior of the proposed oscilloscope with respect to the standard DSO.

Another set of experiments included signal input from various standard as well as non-standard sources. These signals mostly consisted of responses from actual engineering systems like mobile robots – sensor data, controller input and output, feedback signals, etc. Acquisition of these signals was tested in terms of parameter accuracy and noise ratio. Overall performance of the designed oscilloscope was determined based on accuracy of displayed waveform and resolution of stored data.

IV. RESULTS AND DISCUSSION

The virtual and standard DSO exhibited very small deviation in terms of output waveforms obtained from the experiments. Table 2 displays peak-to-peak voltages and frequencies of signals analyzed on the standard and the virtual DSOs. Voltage axis had an error of 1.3% and while no particular error was observed for time axis, the fact that virtual DSO could not analyze signals beyond 10 kHz, as opposed to 70 MHz for its counterpart, was a limiting factor for the design.

Table 2. Experiment Results

Signal	Keysight DSO		Virtual DSO	
	$V_{p\text{-}p}$	Frequency	$V_{p\text{-}p}$	Frequency
DC	80 mV	-	100 mV	-
Pulse	4.54 V	1.00 Hz	4.60 V	1.00 Hz
Square	4.54 V	1.00 Hz	4.60 V	1.00 Hz
Triangle	4.54 V	1.00 Hz	4.60 V	1.00 Hz
Ramp	4.54 V	1.00 Hz	4.60 V	1.00 Hz
Sine	4.54 V	1.00 Hz	4.60 V	1.00 Hz

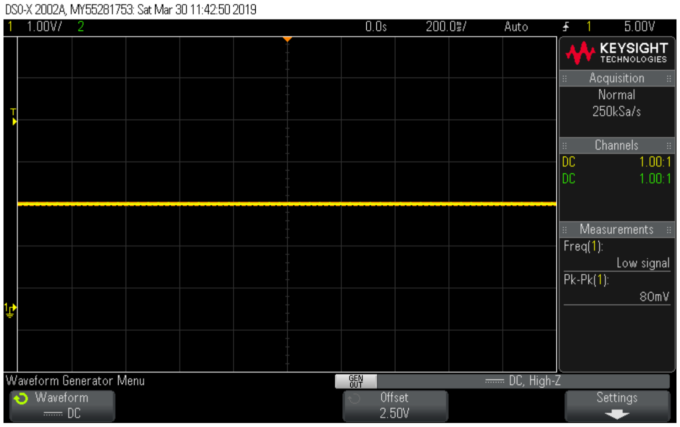


Fig. 8. DC signal with 5 V amplitude and 2.5 V offset as observed on the Keysight InfiniiVision DSO-X 2002A

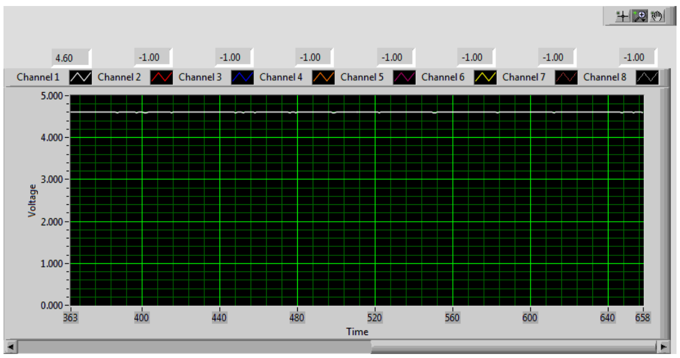


Fig. 9. 5 V DC signal as observed on virtual DSO

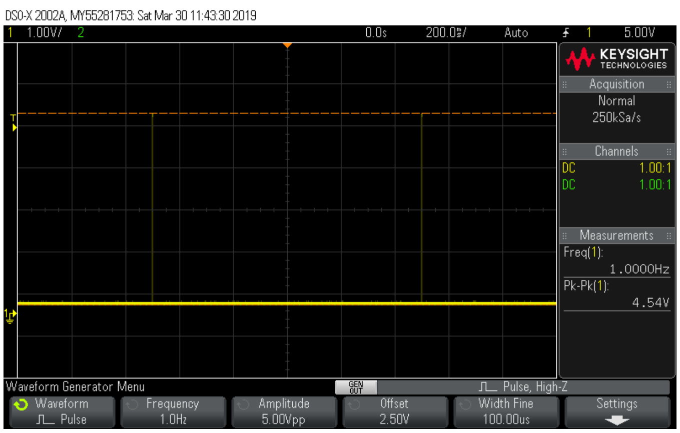


Fig. 10. Pulse signal of 100 µs pulse width with 5 V amplitude, 1 Hz frequency and 2.5 V offset as observed on the Keysight InfiniiVision DSO-X 2002A

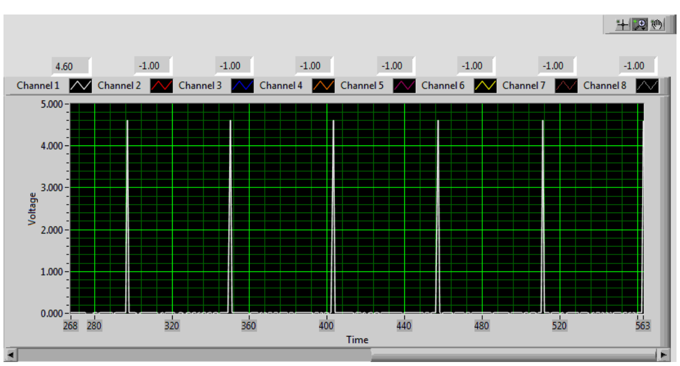


Fig. 11. 5 V, 1 Hz pulse signal of 100 µs pulse width as observed on the virtual DSO

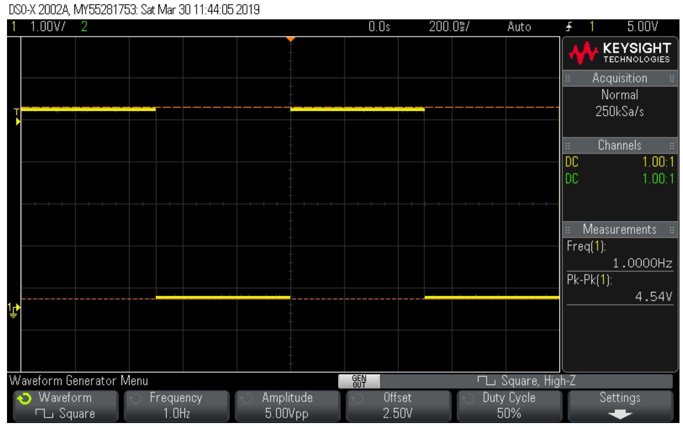


Fig. 12. Square wave of 50% duty cycle with 5 V amplitude, 1 Hz frequency and 2.5 V offset as observed on the Keysight InfiniiVision DSO-X 2002A

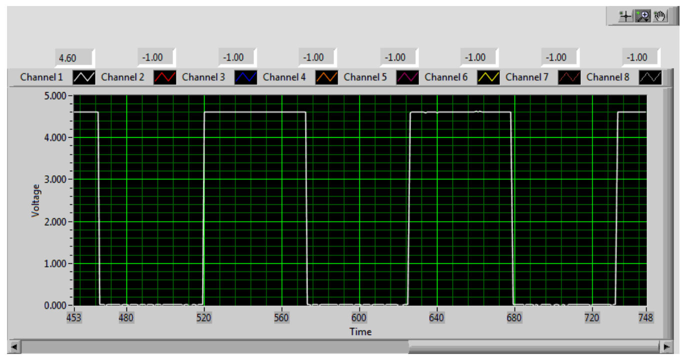


Fig. 13. 5 V, 1 Hz square wave of 50% duty cycle as observed on virtual DSO

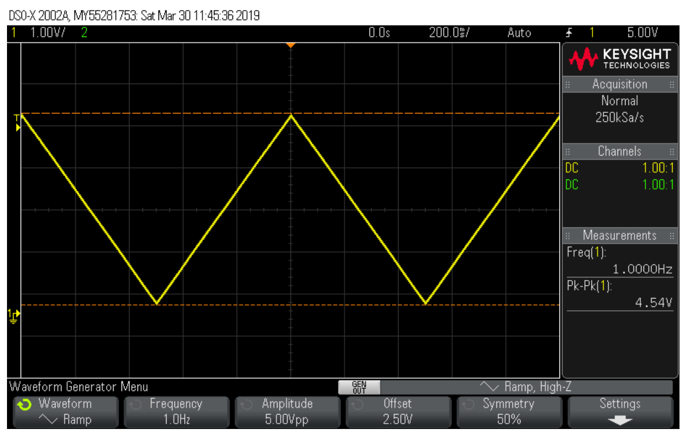


Fig. 14. Triangle wave of 50% symmetry with 5 V amplitude, 1 Hz frequency and 2.5 V offset as observed on the Keysight InfiniiVision DSO-X 2002A

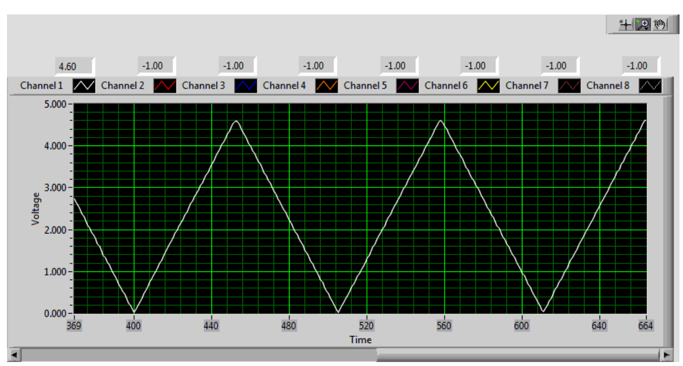


Fig. 15. 5 V, 1Hz triangle wave of 50% symmetry as observed on the virtual DSO

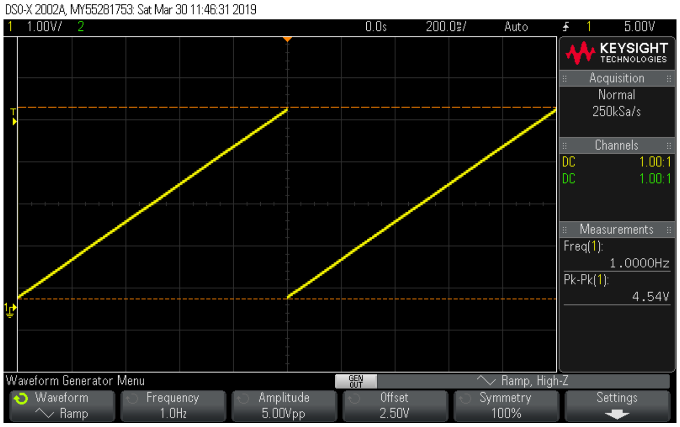


Fig. 16. Ramp wave of 100% symmetry with 5 V amplitude, 1Hz frequency and 2.5 V offset as observed on the Keysight InfiniiVision DSO-X 2002A

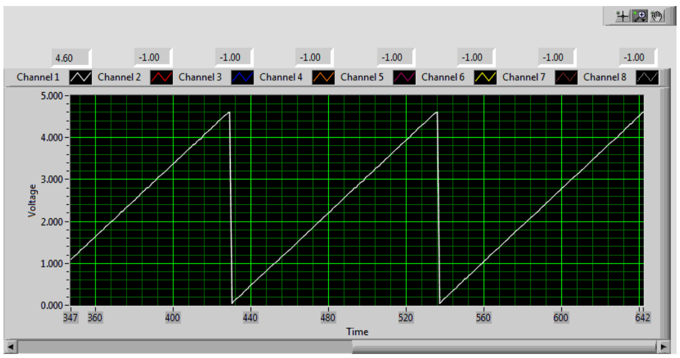


Fig. 17. 5 V, 1 Hz ramp wave of 100% symmetry as observed on the virtual DSO

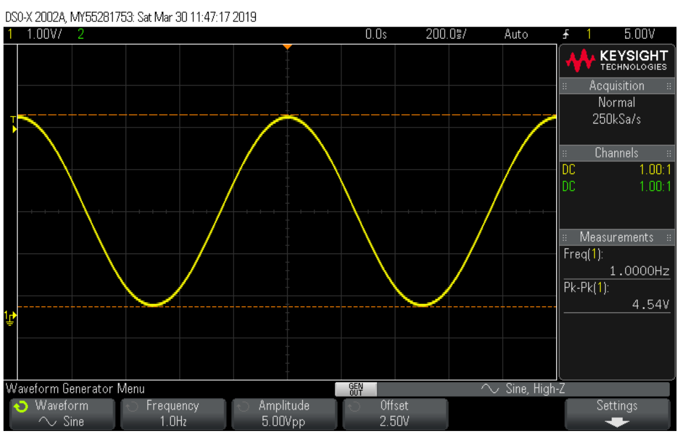


Fig. 18. Sine wave with 5 V amplitude, 1Hz frequency and 2.5 V offset as observed on the Keysight InfiniiVision DSO-X 2002A

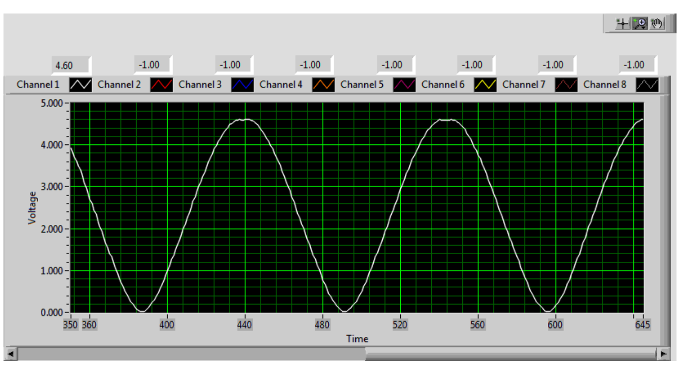


Fig. 19. 5 V, 1 Hz sine wave as observed on the virtual DSO

V. CONCLUSION

The virtual instrument as well as hardware interfacing unit of a DSO was designed and its performance analysis exhibited optimal behavior in response to input signals. The tolerance limits of the designed virtual DSO lied within the range of mere $\pm 1.3\%$; however, the sampling rate was limited to just 10 kHz and the DSO could only analyze voltage signals between 0 V and 5 V DC; both the restrictions being imposed due to the microcontroller's limitations.

Future works of this project include adopting sophisticated data acquisition system with high resolution ADC in order to achieve higher bandwidth and acquire AC and DC signals of greater magnitude, and adding more features to the virtual instrument such as transforms, time-domain analysis, frequency-domain analysis, virtual function generator, etc.

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