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UNIVERSITY OF YAOUNDE I
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Filière
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Design and Implementation of a Medium Frequency Smart Digital Oscilloscope

A dissertation submitted in partial fulfillment of the requirements for the award of a
Teacher's Diploma for Technical and Professional Education Grade II (DIPETP II) in
Electrical Engineering

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DEDICATION

To my family

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Abstract

Oscilloscopes are used to observe graphical representations of electrical signals changing over time. In case of a voltage signal, the voltage against time graph describes a shape which is continuously graphed against a calibrated scale. The oscilloscope is an indispensable tool in electronics when it comes to detecting faults in electric circuits. It is also an important device in the field of metrology and instrumentation. Due to its size, cost and complex structure, an alternative solution is therefore needed. Our work is focused on the new technology used to observe the waveform of an electrical signal using Arduino and LabVIEW. The goal is to visualize analog signals on a virtual oscilloscope. It consists of using Arduino Uno board together with voltage and current sensors for data acquisition of analog signals and viewing waveforms on a virtual oscilloscope developed by LabVIEW software. Between the two tools (LIFA – LabVIEW Interface for Arduino and LINX) presented, the approach with LINX is preferred because it supports acquisition with medium frequency signals whereas LIFA supports low frequencies; moreover, LIFA no longer gets updates and the replacement is now LINX which has more features and hardware support. Analog signals were acquired from the 5 V and 3.3 V Arduino DC supply and also from the AC supply with a lamp connected to the current sensor. The waveforms displayed on the virtual oscilloscope from the voltage and current sensors present a stable DC nature and a slightly distorted AC nature. In order to improve the quality of the waveform of AC nature, a digital filter from the LabVIEW software was used. Despite the relatively moderate speed of data acquisition from the Arduino Uno board, the results obtained show that the virtual oscilloscope effectively displays waveforms and so can be used as an alternative to the analog and digital oscilloscope for educational and research purposes. In view of enhancing learning and the training of student teachers, the proposed oscilloscope can serve as a device for practical instrumentation.

Keywords: Oscilloscope; Waveform; Voltage; Current; Sensor; LabVIEW; Arduino.

Résumé

Les oscilloscopes sont utilisés pour observer les représentations graphiques des signaux électriques changeant au fil du temps. Dans le cas d'un signal de tension, le graphique de la tension dans le temps décrit une forme qui est continuellement représentée sur une échelle étalonnée. L'oscilloscope est un outil indispensable en électronique pour détecter les défauts dans les circuits électriques. C'est aussi un dispositif important dans le domaine de la métrologie et de l'instrumentation. En raison de sa taille, de son coût et de sa structure complexe, il est nécessaire de chercher une solution de rechange. Notre travail est axé sur la nouvelle technologie utilisée pour observer la forme d'onde d'un signal électrique en utilisant Arduino et LabVIEW. L'objectif est de visualiser les signaux analogiques sur un oscilloscope virtuel. Il consiste à utiliser la carte Arduino Uno ainsi que des capteurs de tension et de courant pour l'acquisition de données de signaux analogiques et la visualisation de formes d'onde sur un oscilloscope virtuel développé par le logiciel LabVIEW. Entre les deux outils (LIFA – LabVIEW Interface for Arduino et LINX) présentées, l'approche avec LINX est privilégiée car elle prend en charge l'acquisition avec des signaux de fréquence moyenne alors que LIFA prend en charge les fréquences basses ; en outre, LIFA ne reçoit plus de mises à jour et le remplacement est maintenant LINX qui a plus de fonctionnalités et de soutien matériel. Les signaux analogiques ont été acquis à partir de l'alimentation 5 V et 3,3 V de la carte Arduino et aussi à partir de l'alimentation CA avec une lampe connectée au capteur de courant. Les formes d'onde affichées sur l'oscilloscope virtuel à partir des capteurs de tension et de courant présentent une nature DC stable et une nature AC légèrement déformée. Afin d'améliorer la qualité de la forme d'onde de nature AC, un filtre numérique du logiciel LabVIEW a été utilisé. Malgré la vitesse relativement modérée de l'acquisition de données de la carte Arduino Uno, les résultats obtenus montrent que l'oscilloscope virtuel affiche efficacement des formes d'onde et peut donc être utilisé comme une alternative à l'oscilloscope analogique et numérique à des fins éducatives et de recherche. En vue d'améliorer l'apprentissage et la formation des élèves enseignants, l'oscilloscope proposé peut servir de dispositif d'instrumentation pratique.

Mots-clés : Oscilloscope; Forme d'onde; Tension; Courant; Capteur; LabVIEW; Arduino.

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List of Abbreviations

AC: Alternating Current

ADC: Analog Digital Converter

CRT: Cathode Ray Tube

DC: Direct Current

DSP: Digital Signal Processing

PC: Personal Computer

RMS: Root Mean Square

VI: Virtual Instrument

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GENERAL INTRODUCTION

The measurement of electrical quantities is very important and is even the main subject of a whole branch of Electrotechnics; namely metrology and instrumentation. This field very often uses sensors to produce electrical signals (voltage, current) under the effect of a physical quantity (temperature, sound, pressure, irradiation etc.). When these electrical signals vary over time, they can be viewed using an oscilloscope. This is an indispensable tool in electronics. The oscilloscope is a graph displaying device. It draws the graph of an electrical signal.

Virtual instrumentation has many advantages including: no requirement for physical storage space; possibility of carrying out multiple measurements at once; flexibility of tool configuration; easy processing and manipulation of data (the measuring lab can be located in a certain place and the analysis of the results can be done in a completely different way); significant cost reduction (a single multifunctional acquisition board with the associated software can replace a lot of other dedicated physical tools) [1].

The oscilloscope is a fairly sophisticated and expensive measuring device and therefore a student cannot afford to have it. The latter does not have enough means. Hence the need to use the virtual digital oscilloscope implemented on PC. An important aspect to consider when designing a virtual digital oscilloscope implemented on the PC is the speed of execution of the data acquisition board. This speed depends on the number of channels used and also the board type.

The use of the computer tool (PC, simulation software) in electrical engineering in practical laboratory work for analysis, the representation of the data and the preparation of the reports was a source of motivation for the realization of a digital oscilloscope based on the LabVIEW software that can be implemented on PC.

This dissertation is organized into 3 main chapters: the first chapter is all about the general concepts on the oscilloscope, it also presents some realization of the virtual oscilloscope by different others; chapter 2 gives a detail on the different materials used and the methodology to arrive at the results. As for the last chapter, it gives an analysis on the different results obtained after testing the virtual oscilloscope. It ends with a general conclusion, where we give a general appreciation of the virtual instrumentation device obtained.

CHAPTER 1: LITERATURE REVIEW

Introduction

In this section we give the general concepts on the oscilloscope, followed by some major works that have been done by different authors as far as the virtual oscilloscope implemented on PC is concerned.

1. General concepts on oscilloscopes

1.1. History and evolution

It is very difficult to define an inventor of the oscilloscope. This device stems from several discoveries of the late 19th century.

Around 1878, the British physicist and chemist William Crookes (1832-1919) invented the tube that bears his name. This experimental device is a fundamental element in the genesis of the oscilloscope since it is the origin of cathode ray tubes.

Figure 1.1: First functional oscilloscope [2]

In 1893, the French physicist André Blondel (1863-1938) designed a device to visualize the image of a periodic signal using an optical process: the galvanometric oscillograph. Other mechanical and optical devices appeared at the same time. These devices of delicate use only concern slow signals.

Figure 1.2: Galvanometric Oscillograph [2]

The German physicist Karl Ferdinand Braun (1850-1918) conceived in 1897 a device often considered as the ancestor of the cathode ray oscilloscope. It is then mainly a scientific curiosity.

Figure 1.3: The Braun device [2]

Perfected by many inventors, the Braun device is at the origin of the first oscilloscopes that allow the visualization of signals with a cathode ray tube around 1930. The oscilloscope became truly a measuring device from the Second World War. The device gradually improved to become the basic tool of the electronics technician from the 1960s.

An important limitation of the analog oscilloscope is to allow only the observation of periodic voltages. This type of device is now in the process of extinction because it is supplanted by the digital oscilloscope which offers much wider possibilities.

Advances in digital technology have profoundly changed all electronics since the 1980s. The first digital oscilloscope was developed by LeCroy in 1986. This is a revolution in the history of oscilloscopes because the principle is totally different from that of analog oscilloscopes: the voltage is digitized and then memorized before being processed and displayed. This opens up new possibilities because it is no longer necessary that the signal to be viewed is periodic. However, the performance of the device remains lower than that of analog oscilloscopes, particularly for the observation of periodic high frequency signals. The first digital oscilloscopes are expensive and their use requires some learning. The device remains heavy and cumbersome because the visualization is always done with a cathode ray tube.

Figure 1.4: Cathode Ray Tube [3]

In the last decade of the 20th century, analog oscilloscopes and digital oscilloscopes coexisted. Some models are mixed, that is, analog or digital at the user's choice. The performance of digital oscilloscopes is improving and reaching that of analog devices. An important turning point is the appearance of liquid crystal screens that lead to the creation of light and space-saving oscilloscopes. This allows the application areas of these devices to be expanded to become portable. The use of digital oscilloscopes has gradually been simplified and costs have fallen.

Today, digital oscilloscopes have become widely used devices, not only in their traditional field of use, electronics, but also in all applications where it is necessary to visualize electrical quantities: electrical engineering, automotive, medicine, etc. They are present in research laboratories as well as on construction sites.

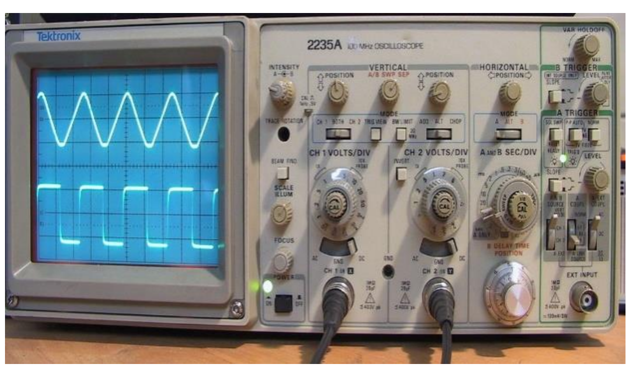


Figure 1.5: Tektronix Analog Oscilloscope [4]

Figure 1.6: LeCroy Digital Oscilloscope [5]

1.2. Types of oscilloscopes

Oscilloscopes can be classified similarly as **analog** and **digital types**. For many applications, either an analog or digital oscilloscope will do. However, each type has unique characteristics that may make it more or less suitable for specific applications. Digital oscilloscopes can be further classified into digital storage oscilloscopes (DSOs), digital phosphor oscilloscopes (DPOs) and sampling oscilloscopes [6].

For many applications, both types can be used. However, each type has specific characteristics more or less adapted to the signals to be measured. Analog oscilloscope is often preferred over digital oscilloscope when it is important to visualize variable signals very quickly over time.

Digital oscilloscopes capture unique events. They can process digital data and transmit it to a computer for processing. They can also store digital data in memory for later review or allow it to be printed on a printer.

1.2.1. Analog oscilloscope

1.2.1.1. How analog oscilloscope works

An analog oscilloscope operates by electric deflection of an electron beam as a function of the measured voltage. The voltage deflects the beam from top to bottom proportionally and traces a curve on the screen that gives an instant (real-time) image of the signal.

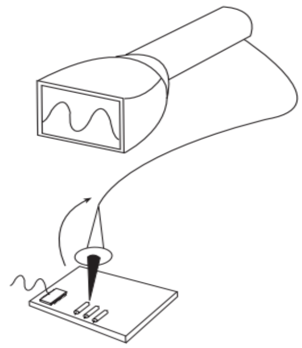


Figure 1.7: How the analog oscilloscope works [**6**]

1.2.1.2. Block diagram of an analog oscilloscope

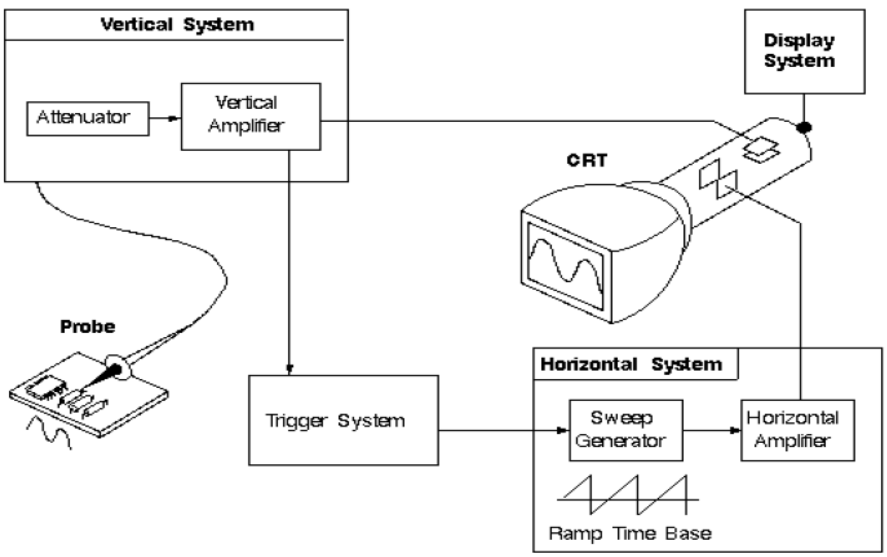


Figure 1.8: Block diagram of analog oscilloscope [6]

The figure above shows that the input signal is applied to the vertical axis of a cathode ray tube. This is the right model for an analog oscilloscope. The important thing to learn from this diagram is that the input signal will be actuated by the oscilloscope vertical axis circuits so that it can be displayed by the CRT.

The analog oscilloscope contains four basic circuit blocks: the vertical amplifier, the time base, the trigger and the display.

Of the four basic blocks, the most visible is the **display** with its cathode ray tube (CRT). It is the component of the oscilloscope that produces the graphical display of the input voltage and is the component with which the user has the most contact.

The **vertical amplifier** conditions the input signal so that it can be displayed on the cathode ray tube. The vertical amplifier provides volt controls by division, position, and coupling, allowing the user to get the desired display. This amplifier must have a sufficiently high bandwidth to ensure that all of the input signal's frequency components reach the CRT.

The **trigger** is responsible for starting the display at the same point of the input signal each time the display is refreshed. It is the stable display of a complex waveform that allows the user of an oscilloscope to make judgments about this waveform and its implications for the functioning of the tested device.

The final part of the block diagram is the **time base**. This circuit block is also known as the horizontal system in some works. The time base is the part of the oscilloscope that displays the input signal as a function of time. The circuits in this block ensure that the CRT beam is deflected from left to right when the input signal is applied to the vertical deflection section of the CRT.

1.2.2. Digital oscilloscope

1.2.2.1. How a digital storage oscilloscope works

On the other hand, a digital oscilloscope samples the signal and uses an analog-to-digital converter (CAN) to convert the voltage to be measured to digital information. It then uses this digital information to reconstruct the curve on the screen.

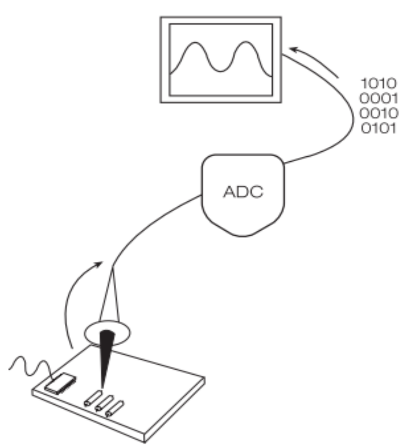


Figure 1.9: How digital storage oscilloscope works [6]

1.2.2.2. Block diagram of the digital storage oscilloscope

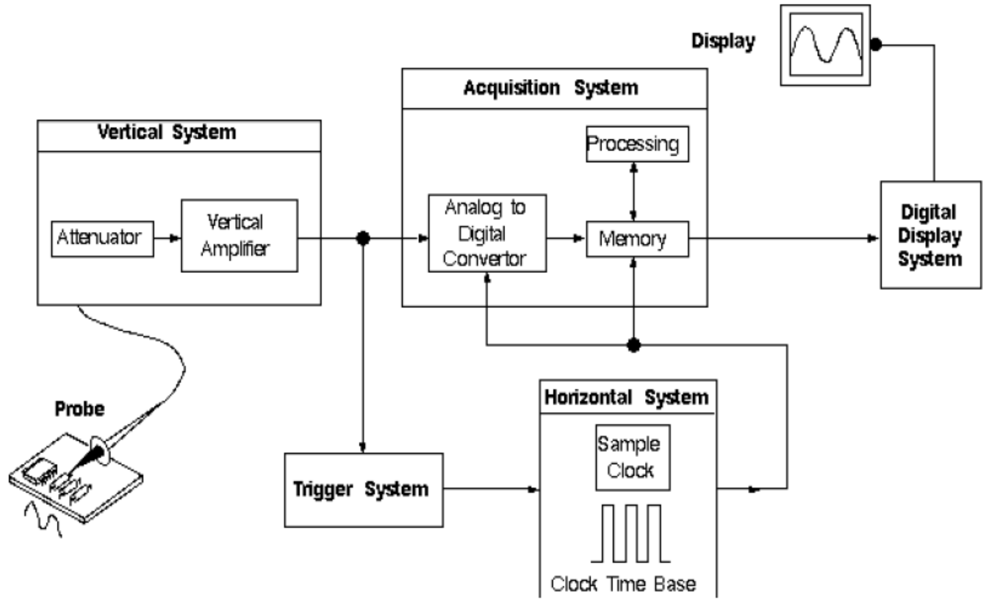


Figure 1.10: Block diagram of digital storage oscilloscope [6]

From the figure above the **vertical system** is the entry point for the signals coming from the probe. It optimizes the amplitude of the incoming signal to the voltage range of the subsequent circuits, particularly the analog-to-digital converter (ADC). It should introduce no changes to the signal other than deliberate amplitude and offset adjustments.

The **acquisition system** encompasses the time base (or horizontal) elements plus the actual digitizing and storage elements. It samples the signal voltage, acquiring numerous data points to display it. In a digital oscilloscope, the horizontal system contains the sample clock, which gives each voltage sample a precise time (horizontal) coordinate. The sample clock drives an analog-to-digital converter (ADC) whose output is stored in the acquisition memory. The capacity of this memory is known as the record length.

The **trigger system** detects a user-specified condition in the incoming signal stream and applies it as a time reference in the waveform record. The event that met the trigger criteria is displayed, as is the waveform data preceding or following the event. In each case, the trigger event's position in time can be observed. The trigger system ensures that a stable, consistent waveform will be displayed on the screen. The trigger system looks for voltage thresholds, pulse widths, logic combinations (on multiple inputs), and many other conditions to qualify an acquisition.

1.2.2.3. Performance terms of oscilloscopes

- **Bandwidth**

The bandwidth specification tells you the frequency range the oscilloscope accurately measures [7].

- **Rise time**

Rise time may be a more appropriate performance consideration when you expect to measure pulses and steps. An oscilloscope cannot accurately display pulses with rise times faster than the specified rise time of the oscilloscope.

- **Vertical sensitivity**

The vertical sensitivity indicates how much the vertical amplifier can amplify a weak signal. Vertical sensitivity is usually given in millivolts (mV) per division.

- **Vertical resolution**

The resolution, in bits, of the ADC indicates how precisely it can turn input voltages into digital values.

- **Sweep speed**

For analog oscilloscopes, this specification indicates how fast the trace can sweep across the screen, allowing you to see fine details. The fastest sweep speed of an oscilloscope is usually given in nanoseconds/div.

- **Time base**

The time base or horizontal accuracy indicates how accurately the horizontal system displays the timing of a signal.

- **Gain accuracy**

The gain accuracy indicates how accurately the vertical system attenuates or amplifies a signal.

1.4. Comparing the analog and digital oscilloscopes

Table 1.1: Differences between analog and digital oscilloscope [7]

Criteria	**Analog Oscilloscope**	**Digital Oscilloscope**
Analog reading	Directly reads analog voltage and displays on screen	It reads the analog voltage and converts it into digital form before being displayed on the screen
Acquisition of signals	Does not require ADC, microprocessor and acquisition memory	Requires ADC, microprocessor and acquisition memory
Analysis	Can only analyze signals in real time as there is no storage memory available	Can analyze signals in real time as well as can analyze previously acquired large samples of data with facility of storage available
Processing	Cannot process high frequency sharp rise time transients	Cab process high frequency transients due to advanced DSP algorithms available and ported on microprocessor which can operate on stored samples of input voltage

1.5. Classification of signals

1.5.1. Deterministic signals

The deterministic signal is a signal for which at any time instant t the value of $x(t)$are given as a real or complex number. [8] The deterministic signal can be described by mathematical expression, diagram or look up table. For example, the exponential signal $x(t) = e^{-2t}$ is a deterministic signal.

1.5.2. Random or stochastic signals

A random or stochastic signal is a signal for which the value of $x(t)$ cannot be predicted ahead of time or cannot be reproduced using the process of generating the signal. The random signal can be modeled using statistical information about signal. Some common examples of random signals are speech, music, seismic signals.

1.5.3. Periodic and Non-Periodic Signals

A periodic signal is a signal $x(t)$ that satisfies the property $x(t) = x(t + kT_0)$ or all t, and all integers k. T_0 is known as the period of the signal. A signal that does not satisfy the conditions of periodicity is called non-periodic.

1.5.4. Real and Complex Signals

For a given value of the independent variables the values of $x(t)$ can either be real or complex. A real signal takes its values in the set of real number, i.e., $\boldsymbol{x(t)} \in \mathfrak{R}$.A complex signal takes its values in the set of complex numbers, i.e. $\boldsymbol{x(t)} \in \mathbb{C}$

Complex signals are usually used in communications to model signal that convey amplitude and phase information. Like complex numbers, complex signal can be represented by two real signals. These two real signals can be either the real and imaginary parts or the absolute value (or modulus or magnitude) and phase.

1.5.5. Causal and Non-Causal Signals

The concept of causality is an important concept in classifying system. This concept has a close relation to realisability of a system. Causal signals are assumed to be produced by physical devices or systems. The causal signal can exist only at or after the time in which the signal generator is turned on. Signals that are not causal are called non-causal.

1.5.6. Even and odd signals

The signals $x(t)$is even if for all t we have

$$x(-t) = x(t) = x_e(t) \text{ or } x[-n] = x[n] \tag{1.1}$$

and it is odd if for all t

$$x(-t) = -x(t) = x_o(t) \text{ or } x[-n] = -x[n] \tag{1.2}$$

Any signal can be written in terms of its even and odd components

$$x(t) = x_e(t) + x_o(t) \tag{1.3}$$

The even signal has mirror symmetry with respect to the vertical axis.
A signal is odd if it is symmetrical with respect to the origin.

1.5.7. Energy and Power Signals

If $v(t)$ and $i(t)$ are respectively, the voltage and current across a resistor with resistance $R = 1\Omega$ resistor, then the instantaneous power is the average energy expanded over the time interval $t_1 - t_2 = T$

$$p(t) = v(t).i(t) = \frac{1}{R}v^2(t) = v^2(t) \tag{1.4}$$

$$E_x = \frac{1}{T}\int_{t_1}^{t_2} p(t)\,dt = \frac{1}{T}\int_{t_1}^{t_2} v^2(t)\, t_1 \leq t \leq t_2 \tag{1.5}$$

For any signal $x(t)$, the energy E_x is defined as

$$E_x \cong \lim_{T\to\infty} \int_{-T}^{T} |x(t)|^2 dt = \int_{-\infty}^{\infty} |x(t)|^2 dt \quad (1.6)$$

The power P_x of signal is

$$P_x \cong \lim_{T\to\infty} \frac{1}{T} \int_{-T}^{T} |x(t)|^2 dt \quad (1.7)$$

1.6. Types of electric signals and their characteristics

1.6.1. Types of electric signals

A signal is considered to sufficiently represent a given physical quantity and it contains the information to be processed. It is usually an electric voltage, a current, but it can also be an electric or magnetic field [9].

Traditionally, signals are classified into 3 main types:

- Analogue signals;
- Digital signals;
- Power signals;

Depending on how you view this signal and how you want to use it.

1.6.2. Definition of an analog signal

A signal is said to be analog if the amplitude of the carrier magnitude of the information can take an infinite number of values in a given interval. [10]

In its analog form, an electrical signal (voltage or current) can be continuous (if the amplitude is constant over a given time interval) or variable (if the amplitude varies continuously with time). In some cases, the analog signal varies according to simple mathematical laws (sine signal for example).

1.6.3. Characteristics of analog signals

Any electrical signal (voltage or current) is defined by:

- **Its waveform**

The most commonly used forms of signals in electronics are:Sine waves; Square and rectangular waves; Triangle and saw-tooth waves; Step and pulse shapes; Periodic and non-periodic signals; Synchronous and asynchronous signals; Complex waves.

Some of them are illustrated in the figure below.

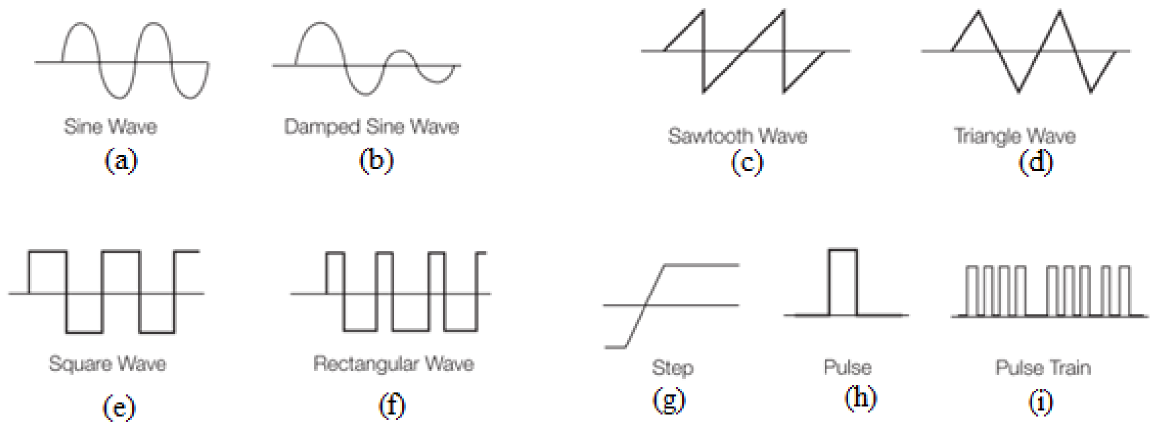


Figure 1.11: Common waveforms of electric signals [11]

- **Its amplitude (or peak-to-peak amplitude)**

The amplitude of a signal is the difference between its maximum and its average value. The peak to peak amplitude of a signal is the difference between its maximum and minimum value.

- **Its period (or frequency)**

The period of a signal is the time at the end of which the signal reproduces identical to itself. The period is marked T, and is expressed in *seconds* (s).

The frequency of a signal is the number of periods in a second. The frequency is recorded f and is expressed in *hertz* (Hz).

- **Its average value**

The mean value is equal to the algebraic surface occupied by the signal during a period, divided by the period of the signal.

- **And possibly its cyclic ratio (in the case of square and rectangular signals)**

A rectangular signal is characterized by 3 time quantities:

The time during which the signal remains at the high level, called high time and noted t_H

The time during which the signal remains low, called low time and noted t_L

The period of the signal noted $\boldsymbol{T}$

The cyclic ratio is only defined for square or rectangular signals.

The cyclic ratio (α) is equal to the ratio between the high time of the signal and its period

$$\alpha = \frac{high\ time}{period\ of\ the\ signal} = \frac{t_H}{T} \tag{1.8}$$

1.7. Analog-to-digital converter

Analog-to-digital converter is electronic integrated circuit which transforms a signal from analog (continuous) to digital (discrete) form [12]. Analog signals are directly measurable quantities. Digital signals only have two states. For digital computer, we refer to binary states, 0 and 1. So the Analog to Digital converter accepts an analog input signal (usually a voltage $V(t)$) and produces a corresponding digital number at the output.

Microprocessors can only perform complex processing on digitized signals. When signals are in digital form they are less susceptible to the deleterious effects of additive noise. ADC Provides a link between the analog world of transducers and the digital world of signal processing and data handling.

ADCs are used virtually everywhere where an analog signal has to be processed, stored, or transported in digital form. There are many applications of ADCs notably: digital voltmeters, cell phone, thermocouples, and digital oscilloscope; just to name a few.

1.7.1. ADC process

The figure below shows the block diagram of the ADC process:

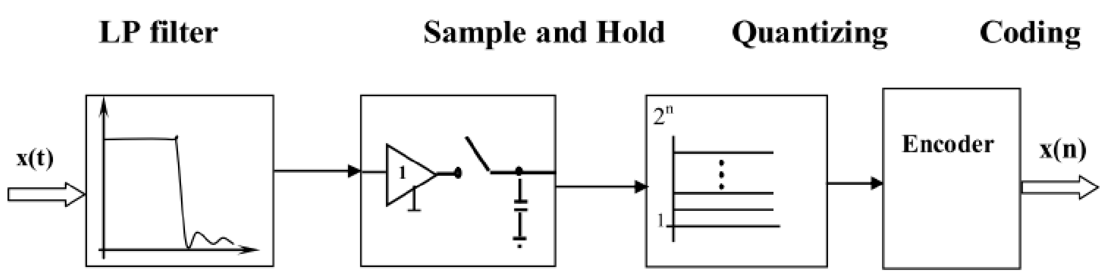


Figure 1.12: Block diagram of the ADC [13]

The role of the Low Pass (LP) filter is to allow the passage of signals with a frequency lower than a selected cutoff frequency and to attenuate signals with frequencies higher than the cutoff frequency. Its characteristics frequency must be $^1/_2$ of sampling frequency f_s.

The ADC process can be summarized in two steps: **Sampling and Holding (S/H); Quantizing and Encoding (Q/E)**

- **Sampling and Holding (S/H)**

The electrical signal is sampled (a sample-hold circuit acquires the signal voltage and then holds its value while an analog-to-digital converter converts the value into digital form).
Holding signal improves the accuracy of the A/D conversion.

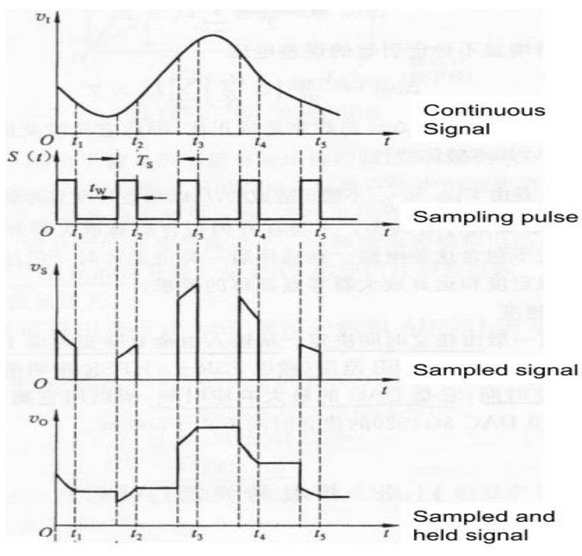


Figure 1.13: Sampling and holding [13]

The minimum sampling rate should be at least twice the highest data frequency of the analog signal. This is in line with Nyquist theorem:
If a continuous bandwidth-limited signal contains no frequency components higher than f_c, then the original signal can be recovered without distortion if it is sampled at a rate of at least $2f_c$ samples per second, thus

$$f_s \geq 2f_c \tag{1.9}$$

- **Quantizing and Encoding (Q/H)**

Quantizing is the process of transforming an analog signal into a set of discrete output states - there are $\mathbf{2^n - 1}$ analog decision points (or threshold levels) in the transfer function (n – number of quantizer bits). Each threshold level corresponds to the number (**code**).

The analog-to-digital converter requires a small amount of time to perform the quantizing and coding operations. The time required to make the conversion depends on: the converter resolution, the conversion technique, and the speed of the components employed in the converter. The conversion speed required for a particular application depends on the time variation of the signal to be converted and on the accuracy desired.

1.7.2. Accuracy of A/D Conversion

There are two ways to best improve the accuracy of A/D conversion:

- Increasing the resolution which improves the accuracy in measuring the amplitude of the analog signal.
- Increasing the sampling rate which increases the maximum frequency that can be measured.

1.8. Data acquisition

The field of data acquisition encompasses a very wide range of activities. At its simplest level, it involves reading electrical signals into a computer from some kind of sensor. These signals may represent the state of a physical process i.e. position and orientation of machine tools, furnace temperature, size and shape of a manufactured component etc. The acquired data may have to be stored, printed or displayed. Often the data have to be analyzed or processed in some way in order to generate further signals for controlling external equipment or for interfacing to other computers. [14]

This may involve manipulating only static readings, but it is also frequently necessary to deal with time-varying signals as well. Some systems may involve data to be gathered slowly, over time spans of many days or weeks. Other will necessitate short bursts of very high speed data acquisition – perhaps at rates of up to several thousand readings per second. DAQ is used widely for laboratory automation, industrial monitoring and control, as well as in a variety of other time-critical applications. The most central reason for using the PC for data acquisition and control is that there is now a large and expanding pool of programmers, engineers and scientists who are familiar with the PC. [14]

A data acquisition and control system typically consist of the following:

- ***Sensors*** which measure physical variables such temperature, strain, pressure, flow, force and motion (displacement, velocity and acceleration).

- ***Signal conditioning,*** to convert the sensor outputs into signals readable by the analog input board (A/D) in the PC.
- An ***analog input (A/D) board,*** to convert these signals into digital format usable by the PC.
- A ***computer*** with the appropriate application software to process, analyze and log the data to disk. Such software may also provide a graphical display of the data.
- An ***output interface,*** to provide an appropriate process control response.

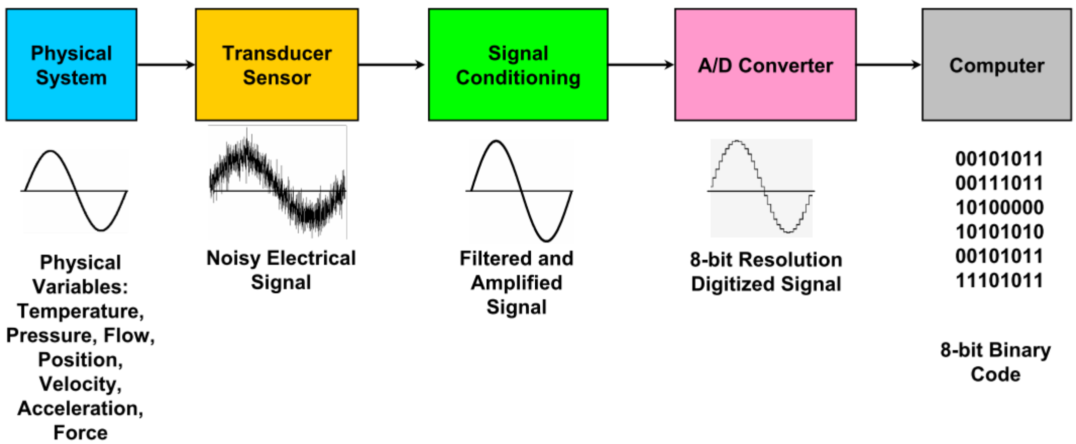


Figure 1.14: Block diagram of Data acquisition system [15]

In order to sense and measure physical variables, it is necessary to use transducers (sensors), which convert physical variables into electrical signals and transmit these signals either to a signal conditioning device or directly to the data acquisition board.

The signal condition device performs the following main functions:

- Supplies power to the transducer, when required;
- Amplifies, filters or digitizes the sensor signal;
- Provides appropriate output signal which is easy to capture with an analog input board.

Signal conditioners must perform these functions over the amplitude and frequency range of the expected input signal.

Signal conditioners have a large effect on the measurement system performance characteristics.

After conditioning, the sensor signal is passed to the analog input (A/D) board.

The A/D board converts the conditioned analog voltage or current into a digital format which is readable by the PC.

An analog signal is continuous-time function with a physical parameter defined for every instance of time. The signal must be converted into a discrete signal so that it can be used by the computer to depict the original.

A/D boards often incorporate some of the capabilities below:

- High-speed data transfer to the PC
- Noise and anti-aliasing filtering
- Programmable gain amplifier
- Circuitry for hardware and software triggering

1.9. Review of articles and dissertations on virtual digital oscilloscope

1.9.1. PC based multi-channel oscilloscope using Arduino

G.Komala Yadav et al (2019)

This work presents a multi-channel oscilloscope implemented on PC from the ARDUINO board. Signals can be captured at frequencies up to 5 kHz. Data playback is possible thanks to the analog-to-digital converter of the Arduino board and this is sent back to the PC via the USB port.

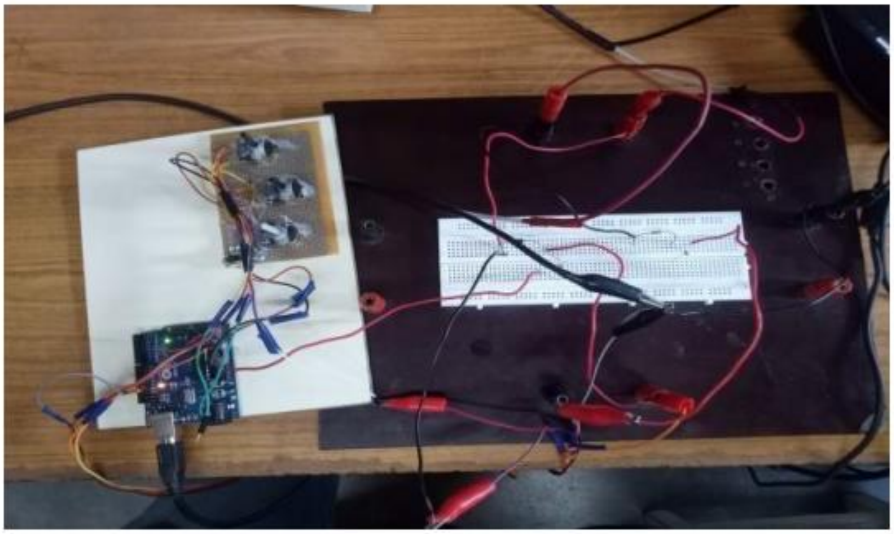


Figure 1.15: Prototype of data acquisition [16]

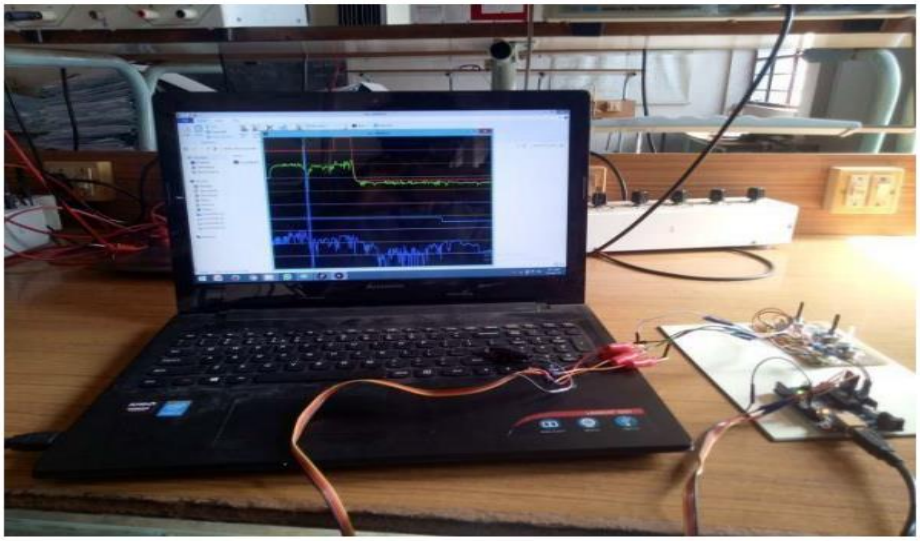


Figure 1.16: Data acquisition and waveform display on PC [16]

1.9.2. Measuring Voltage and Time Quantities of a Signal through a Virtual Oscilloscope

G. Tektas et al (2017)

Here, the virtual oscilloscope is based on LabVIEW software. The measurement of voltage and time (amplitude, climb time, descent time and frequency) is done through a signal from a function generator. The results obtained from the virtual software are identical to the results obtained from two different real oscilloscopes (the GW Instek 2204 and 3504 models). It is also demonstrated from the results obtained that the virtual oscilloscope can be used to visualize the signal shape and measure voltage and time (up and down time) with high precision.

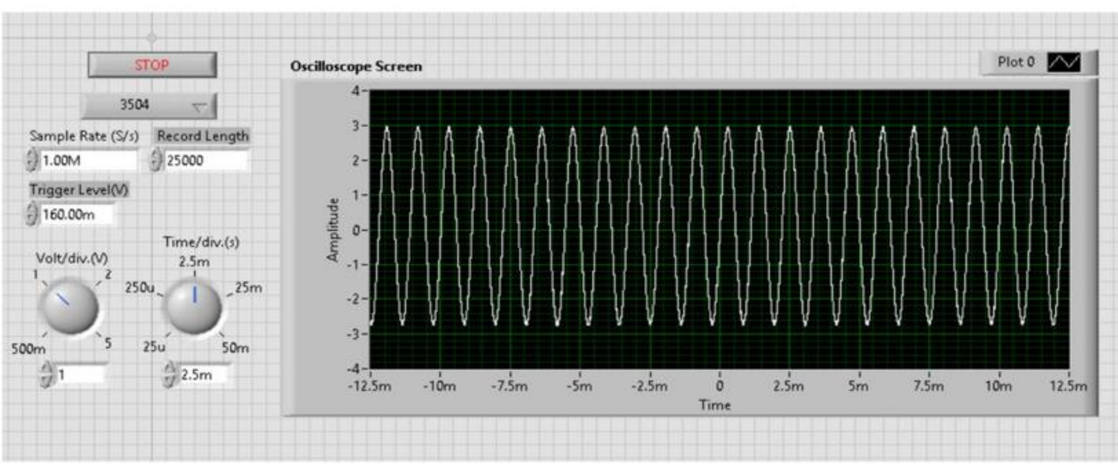


Figure 1.17: Front panel of the virtual oscilloscope [17]

1.9.3. An Approach To Low-Cost Oscilloscope Development at Medium Frequencies Using Led Screen

M.C Ndinechi et al (2012)

This article presents a new approach for the cost-effective development of a medium frequency digital oscilloscope that does not have complex functions but offers appropriate functionality. It uses light-emitting diode technology as a screen instead of a cathode ray tube. The use of Phase Locked Loop (PLL) in its time base generation; produce a range of sweep frequencies with high pulse fidelity. With the use of real-time sampling, the signals are captured as they occur. This bridges the gap between the digital storage scopes and the analogue ones while not involving the complexity in digital phosphor oscilloscope (DOP) development.

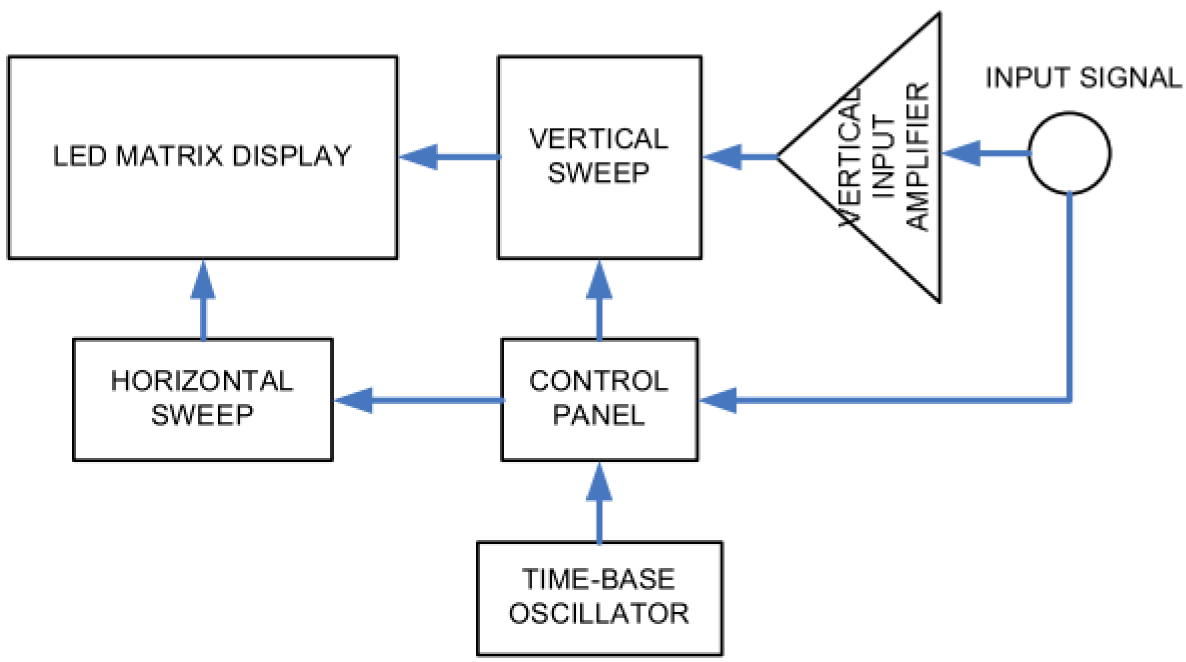


Figure 1.18: Block diagram of LED based oscilloscope [18]

1.9.4. Comparison of a designed virtual oscilloscope with a real oscilloscope

Gozde Tektas et al (2015)

This article presents a virtual oscilloscope designed with LabVIEW software. The sine, square and triangular signals produced by a fun’
ction generator were analyzed with a real and virtual oscilloscope. The amplitude, climb time and descent time values of a signal were determined for different time/division values in both types of oscilloscope. The values obtained in the virtual oscilloscope were compared to those of a real oscilloscope. It was deduced from the results that the amplitude, the time of rise and fall tile and the signal forms were compatible with each other.

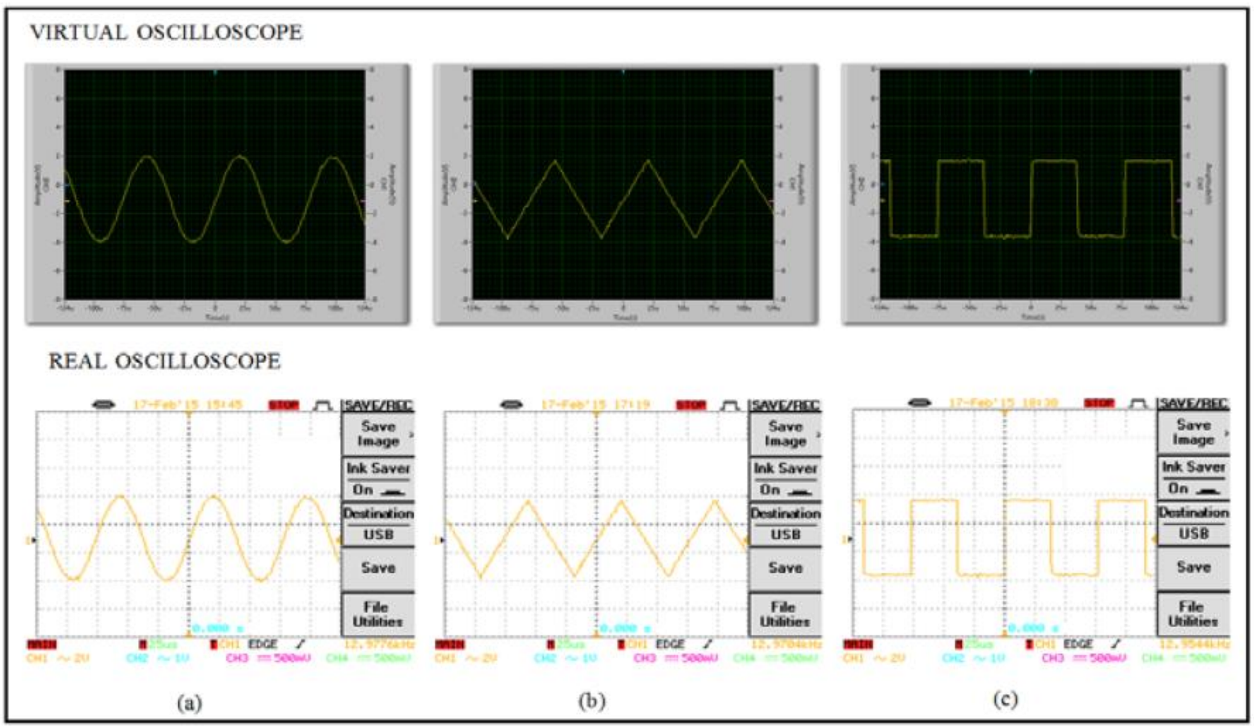


Figure 1.19: Comparison of the virtual and real oscilloscope using sine, triangular and square waveforms [19]

1.9.5. Based on LabVIEW Remote Virtual Electronic Laboratory Design and Implementation

Yongyu Peng et al (2014)

This article is mainly intended for the rapid development of the remote virtual laboratory. This article first analyzes the programming tool of the virtual lab and explains why LabVIEW is chosen. Then, introduce a detailed thinking to make use of the LabVIEW (VI) program functionality that the HTML web page can be inserted easily; remotely design the electrical and virtual electronic laboratory software applicable to electrical and electronic education experience in universities. Finally, this article shows that the rapid establishment of a remote virtual laboratory by LabVIEW is both feasible and simple.

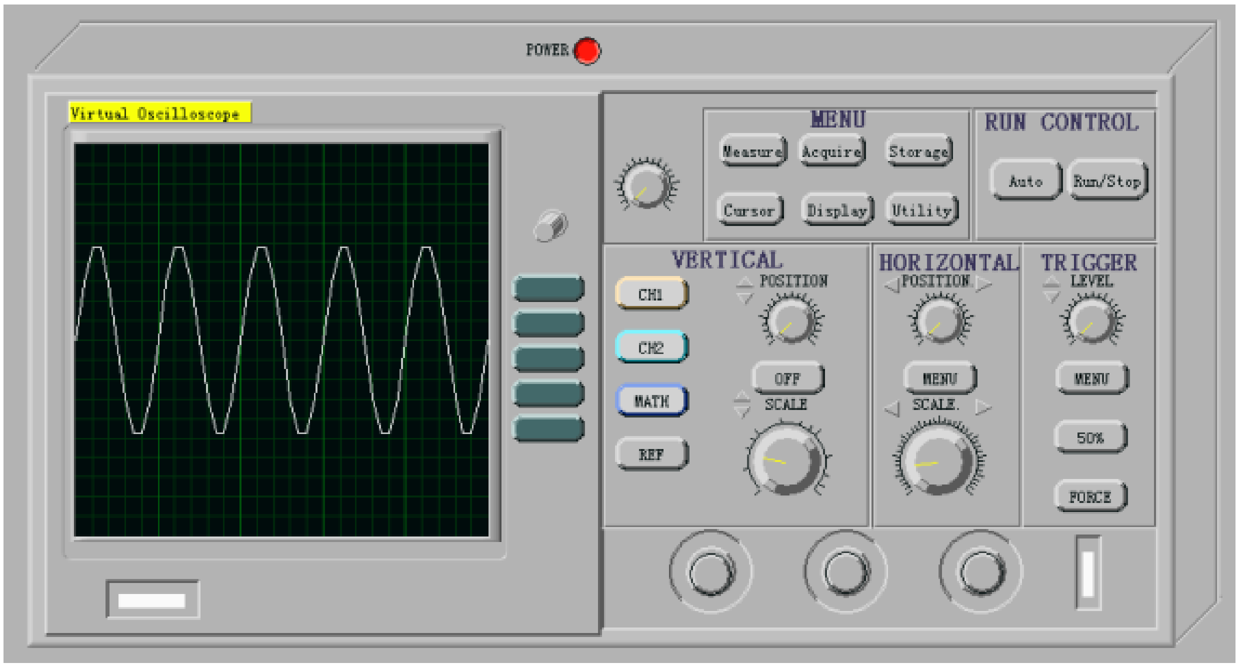
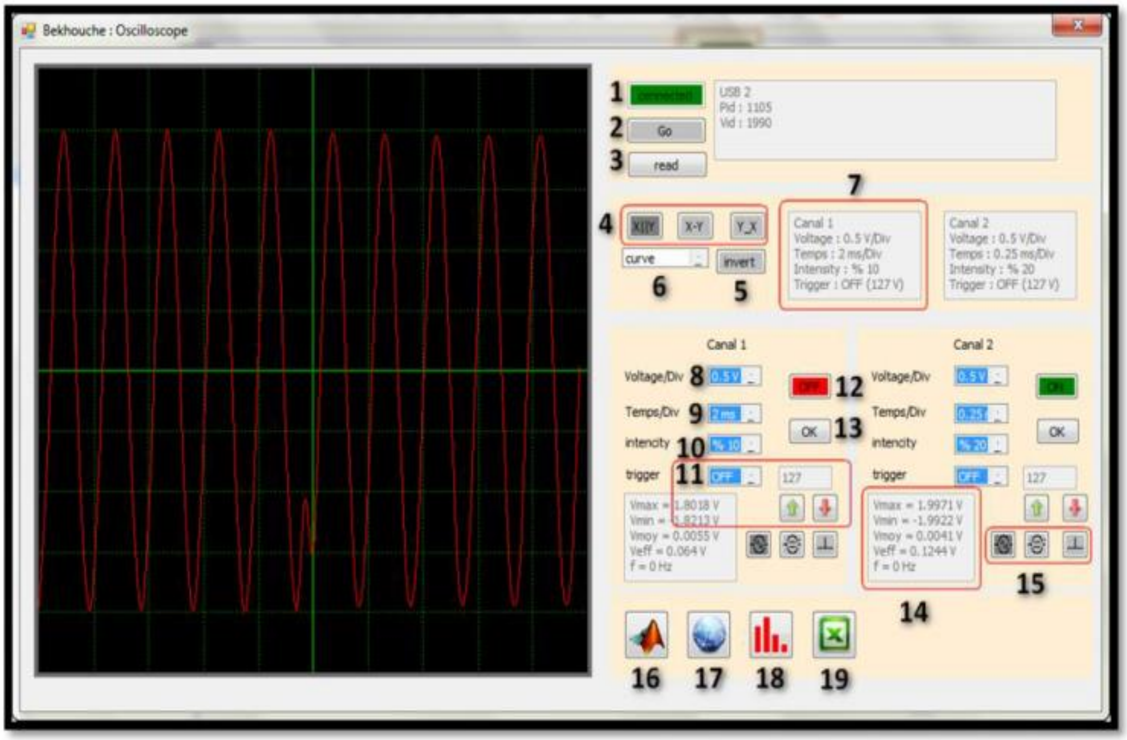


Figure 1.20: Oscilloscope virtuel [20]

1.9.6. Realization of a portable digital oscilloscope with PC display via USB port

Bekhouche Salah Eddine (2013)

This thesis presents the realization of a portable digital oscilloscope. The scope realized in this project is connectable to the PC using the Universal Serial Bus (USB). The user interface, performed under the C# environment, controls communication with the acquisition board whose core is the 18F4550 PIC. The frequency of the acquired signal is limited by the conversion time of the microcontroller. The data transmission speed between the PC and the PIC, used is 15 Mbps. This can only be achieved with the USB bus and more precisely the USB Full Speed standard. It is important to note that in this work, the use of the serial port was rejected because of the speed values that are allowed.



KEY:
1. USB bus connection button and indicator.
2. Continuous reading and display.
3. Read and display only once.
4. Display mode: y(t), x(y), y(x)
5. Reverse signal.
6. Display style: line, curve.
7. Current channel configuration indicator.
8. Graduation selection.
9. Basic time selection.
10. Intensity adjustment.
11. Trigger: activation, level, front.
12. Set the signal visible or invisible.
13. Validation of the chosen configuration.
14. Signal information: Vmax, Vmin, Veff, Vmoy.
15. Coupling mode selection: AC, DC, GND.
16. Create a MATLAB data file.
17. Connect the oscilloscope to a web-based control and display interface.
18. Spectrum analyzer.
19. Create an Excel data file.

Figure 1.21: User interface [21]

1.9.7. Real-time virtual instrumentation of Arduino and LabVIEW based PV panel characteristics

A El Hammoumi et al. (2018)

This paper describes a virtual instrument based on a low-cost embedded board to monitor and plot the PV panel characteristics under real operation condition. The system design is based on a low-cost Arduino acquisition board in which the ATMega328 microcontroller is integrated. The acquisition is made through a low-cost current and voltage sensors and the data are transmitted in LabVIEW by using LIFA Interface for Arduino. The I-V (current-voltage) and P-V (power-voltage) characteristics for the PV panel, which was processed under actual conditions, can be obtained and plotted directly on a monitoring platform in LabVIEW. The proposed instrument can be used for educational or research purposes using a low-cost hardware without having extensive knowledge about electronic engineering. The present instrumentation technique provides easy access to the collected data for further analysis.

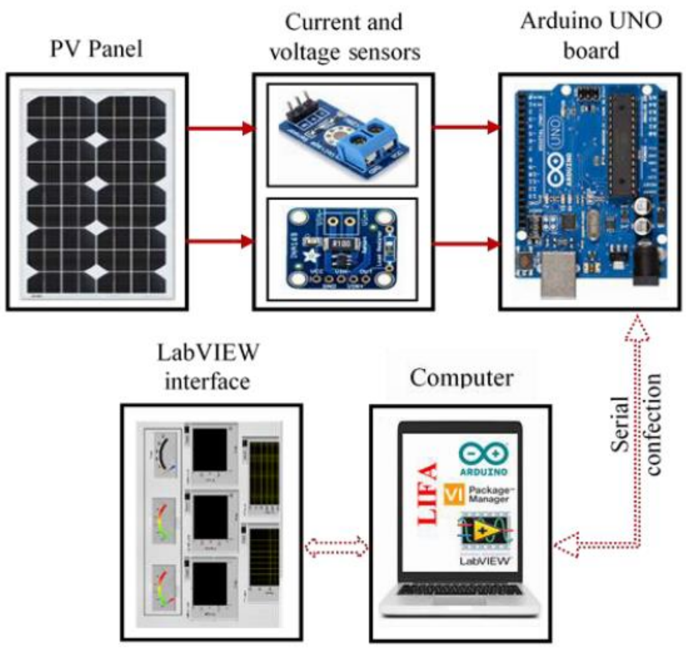


Figure 1.22: Schematic diagram of the PV panel instrumentation system [22]

Conclusion

This chapter has presented the general concepts on the oscilloscope. We gave the difference that exists between the analog and digital oscilloscope. We also presented some virtual instruments that have been proposed by other authors. The chapter that follows will dwell on the materials and method.

CHAPTER 2: MATERIELS AND METHODS

Introduction

In this section we first present the different materials (both hardware and software) used, followed by a brief presentation of the different methods used to design our virtual oscilloscopes. Finally, we give the approach that we adopted in order to realize our virtual instrument with LabVIEW and the data acquisition system using Arduino board, voltage and current sensors.

2.1. Materials

2.1.1. Hardware

The proposed digital oscilloscope consists of an Arduino Uno board, voltage sensor, current sensor and PC.

1. Arduino Uno board

The data acquisition board used to realize our digital oscilloscope is Arduino Uno. This is because it easily accessible and it’s a low-cost board. The figure 2.1 shows the Arduino Uno board and Table 2.1 gives the pin description while Table 2.2 presents its technical specifications.

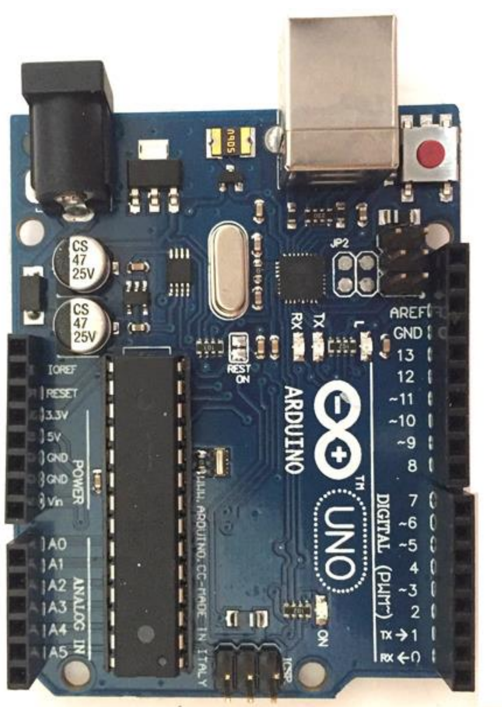


Figure 2.1: Arduino Uno Board [23]

Table 2.1: Arduino Uno Pin description [23]

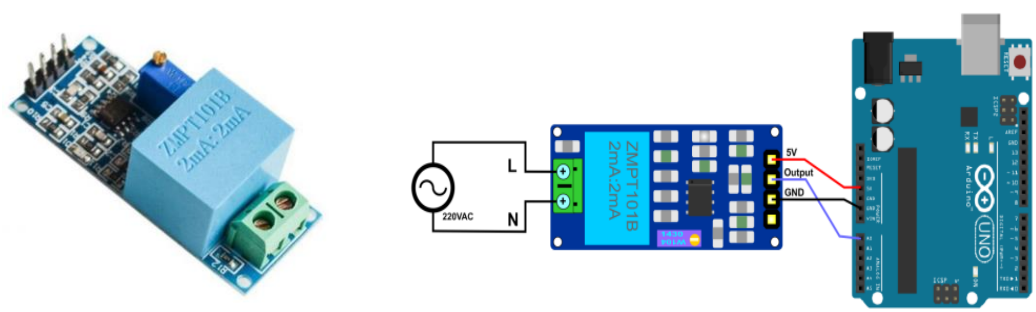
Pin Category	**Pin Name**	**Details**
Power	Vin, 3.3V, 5V, GND	Vin: Input voltage to Arduino when using an external power source. 5V: Regulated power supply used to power microcontroller and other components on the board. 3.3V: 3.3V supply generated by on-board voltage regulator. Maximum current draw is 50mA. GND: ground pins.
Reset	Reset	Resets the microcontroller.
Analog Pins	A0 – A5	Used to provide analog input in the range of 0-5V
Input/output Pins	Digital Pins 0 - 13	Can be used as input or output pins.
Serial	0(RX), 1(TX)	Used to receive and transmit TTL serial data.
External Interrupts	2, 3	To trigger an interrupt.
PWM	3, 5, 6, 9, 11	Provides 8-bit PWM output.
SPI	10 (SS), 11 (MOSI), 12 (MISO) and 13 (SCK)	Used for SPI communication.
Inbuilt LED	13	To turn on the inbuilt LED.
TWI	A4 (SDA), A5 (SCA)	Used for TWI communication.
AREF	AREF	To provide reference voltage for input voltage.

Table 2.2: Arduino Uno technical specifications [23]

Microcontroller	ATmega328P – 8 bit AVR family microcontroller
Operating Voltage	5 V
Recommended Input Voltage	7-12 V
Input Voltage Limits	6-20 V
Analog Input Pins	6 (A0 – A5)
Digital I/O Pins	14 (Out of which 6 provide PWM output)
DC Current on I/O Pins	40 mA
DC Current on 3.3V Pin	50 mA
Flash Memory	32 kB (0.5 KB is used for Bootloader)
SRAM	2 kB
EEPROM	1 kB
Frequency (Clock Speed)	16 MHz

2. Voltage sensor

In order to acquire the AC voltage, the ZMPT101B voltage sensor given in Figure 2.2 (a) is used. Figure 2.2 (b) presents its connection to the Arduino UNO board and the specifications of this sensor are shown in Table 2.3.



(a)

(b)

Figure 2.2: (a) ZMPT101B Voltage sensor Device view, (b) connection to Arduino [24]

Table 2.3: Technical specifications of ZMPT101B voltage sensor [24]

Power supply	250VAC
Rated input current	2mA
Output signal	Analog 0-5V
Size	49.5 mm x 19.4 mm
Operating temperature	40°C to 70 ° C

The ZMPT101B voltage sensor's corresponding analog output can be adjusted. It has good consistency for measuring voltage and power

3. Current sensor

In order to acquire AC analog current signals, the ACS712 current sensor module (Figure 2.3) is used. It is an AC current sensor. In table 2.4, the specifications of the selected current sensor are presented.

Figure 2.3: ACS712 current sensor module [25]

Table 2.4: Technical specifications of ACS712 [25]

Power supply	250VAC
Optimized accuracy range	10 A
Output sensitivity	66 to 185 mV/A
Output signal	Analog 0-5V
Operating temperature	- 40°C to 85 ° C

2.1.2. Software package used

In order to design and implement our digital oscilloscope, we made use of LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench); this software provides virtual instrumentation. With the help of LabVIEW here we are developing a graphical user interface to display the measured parameters (RMS and Mean DC) and also to display the waveform of analog signals derived from the data acquisition card. It has a block diagram coding so it is very easy to use and provides best solutions.

2.2. Method

2.2.1. Methods used to design virtual oscilloscope with Arduino and LabVIEW

In order to design our virtual oscilloscope with Arduino and LabVIEW, there exist 2 methods that are commonly used: LIFA (LabVIEW Interface for Arduino) and LINX. We used the method by LINX because the PC, Arduino Uno board and the sensors responded favorably to this method. Below we give some reasons why we could not opt the method via LIFA.

2.2.2. Problems with LIFA

- LIFA no longer gets updates and the replacement is now LINX which has more features and hardware support.
- LIFA supports low frequencies whereas LINX is suitable for medium frequencies.

2.2.3. Approach used to design our virtual oscilloscope with Arduino and LabVIEW

Before uploading the LINX program into the Arduino Uno board, we developed a synoptic diagram that depicts the principle of our virtual instrumentation device. In Figure 2.4 below, we show how the voltage and current sensors interact with the LabVIEW VI via Arduino Uno board.

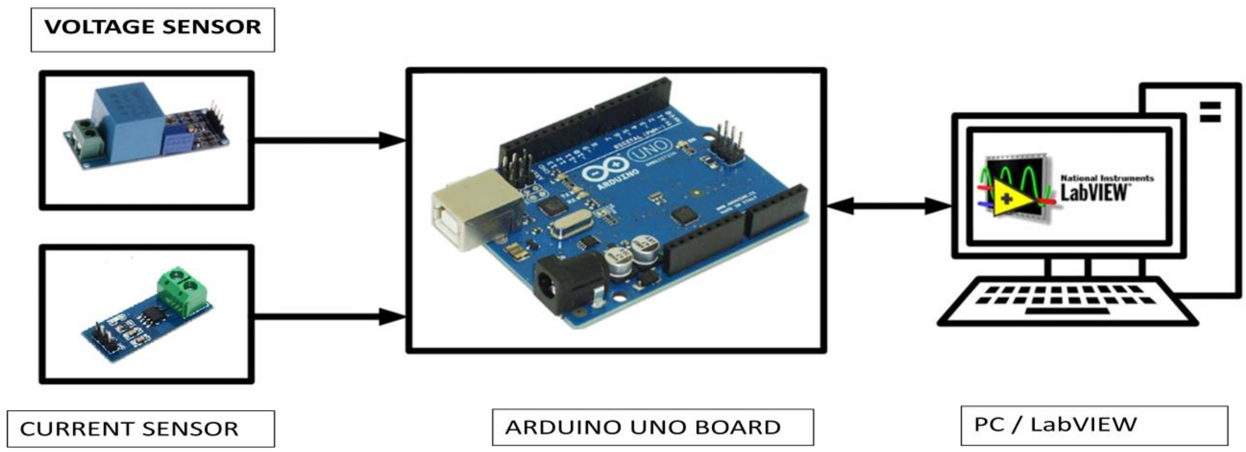
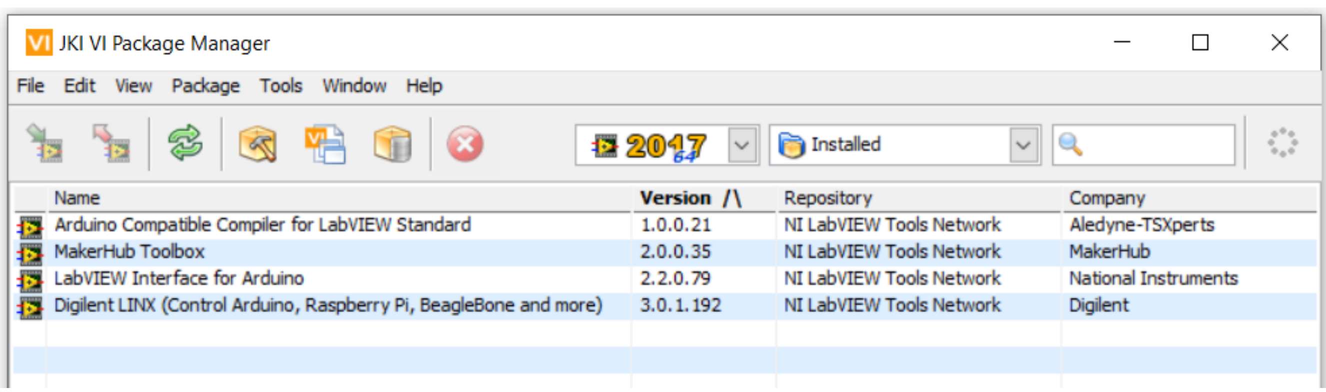


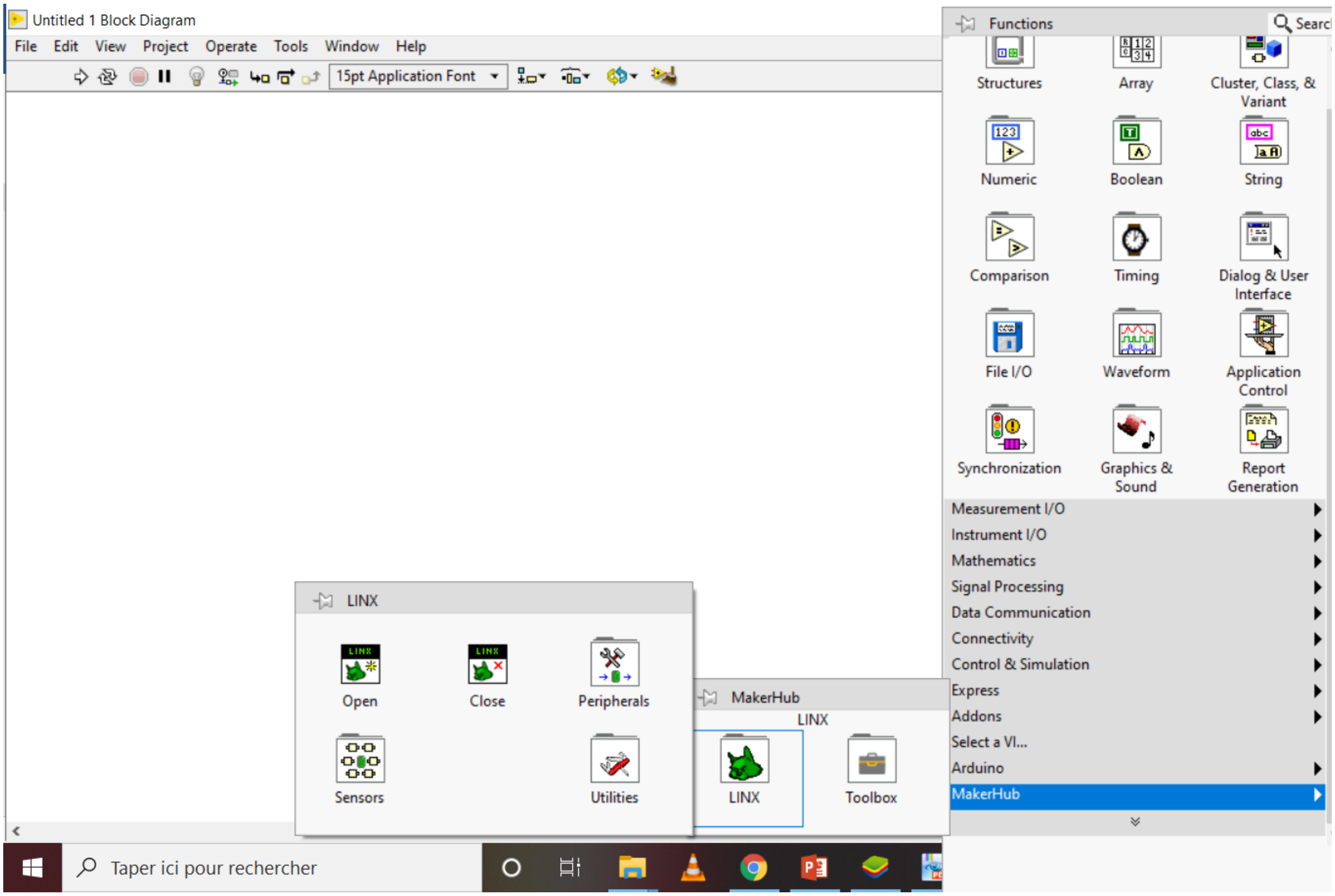
Figure 2.4: Synoptic of block diagram

The following presents the essential steps used to develop our VI:

- **Installed drivers from VI Package**

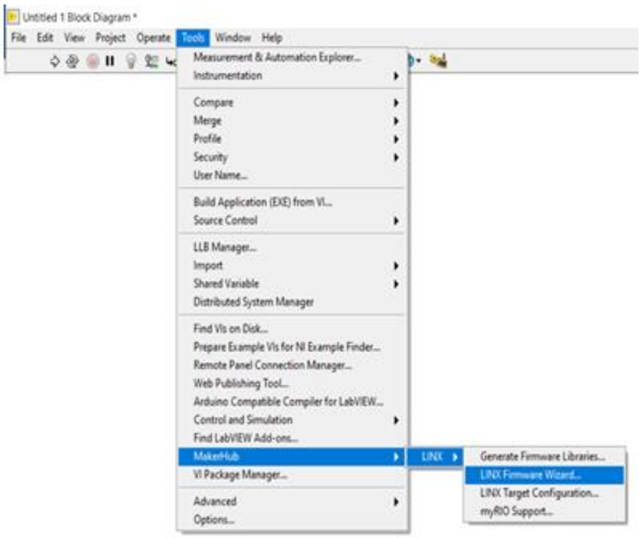


➢ LINX Interface

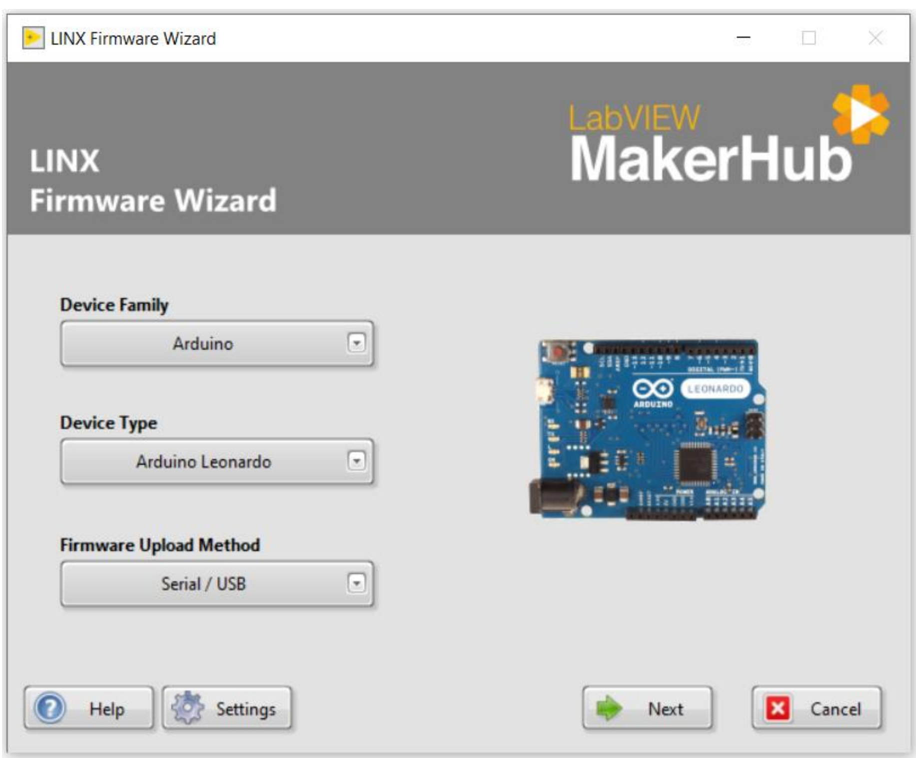


➢ Uploading LINX Firmware

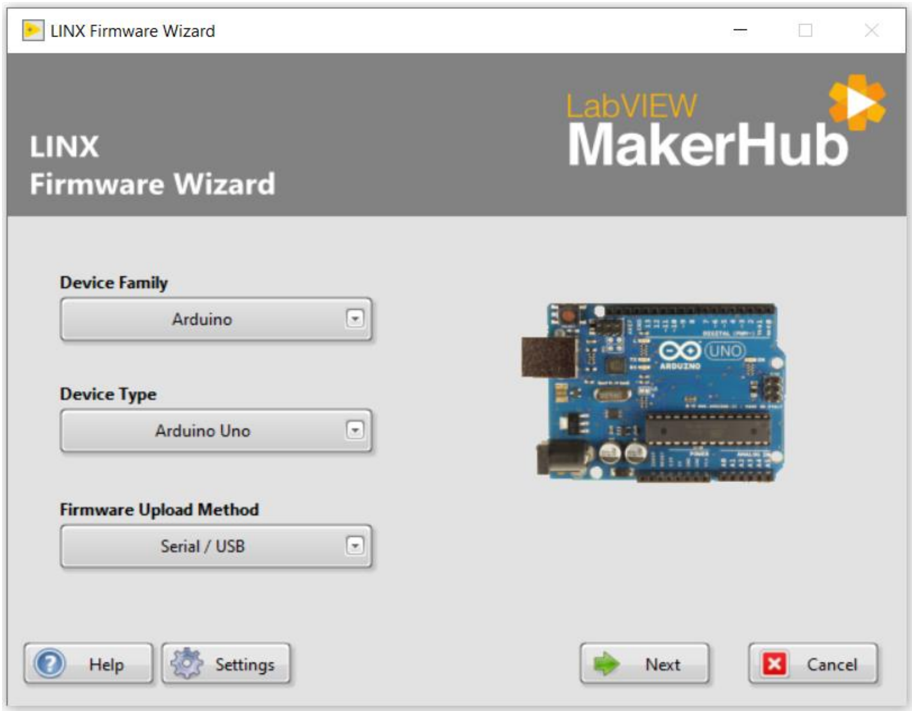
Step 1: Tools → MakerHub → LINX → LINX Firmware



The following will shows the screenshot of what appears after selecting 'LINX Firmware Wizard':

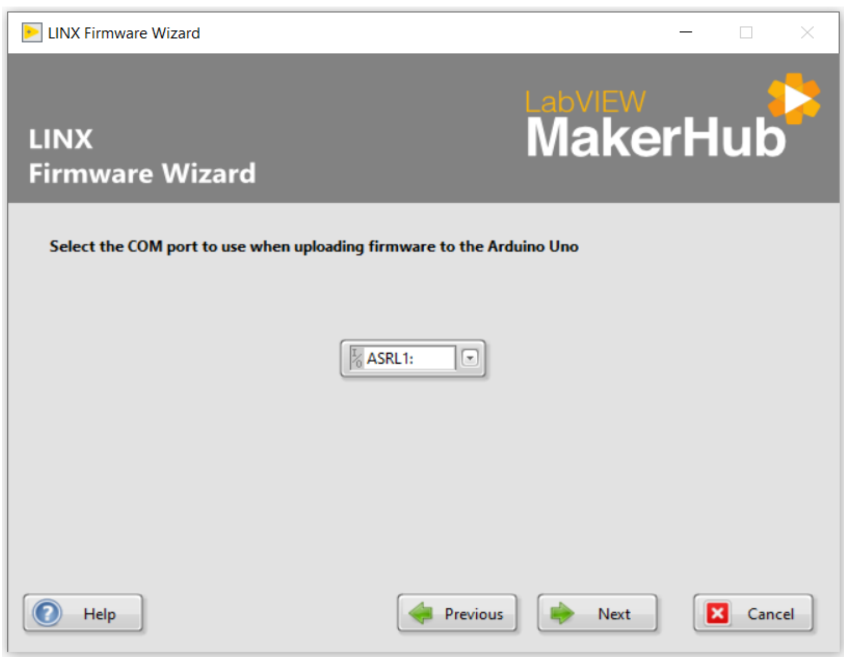


Step 2: Choose Device type (by default Device Family shows Arduino and Firmware upload method is Serial/USB). This is a screenshot that appears after selecting Arduino Uno as device type.



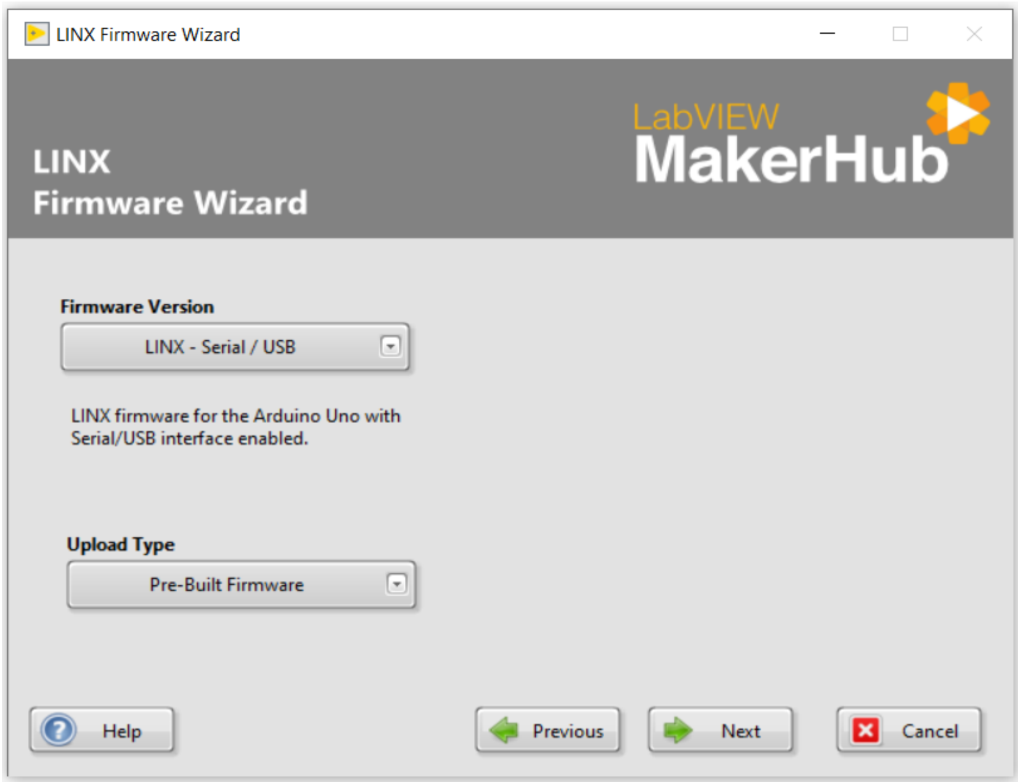
Click on Next;

Step 3: Select the COM Port to which the Arduino board is connected.

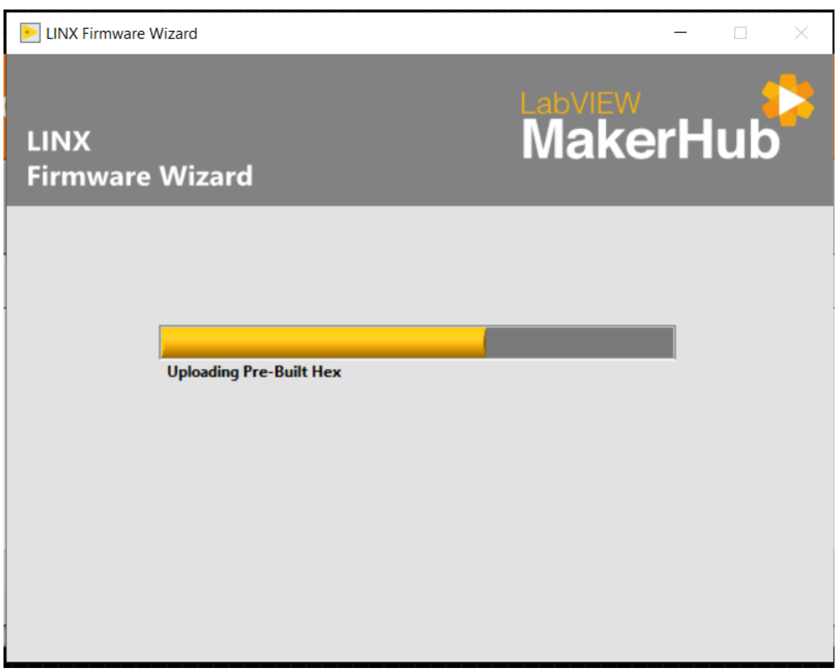


Click on Next;

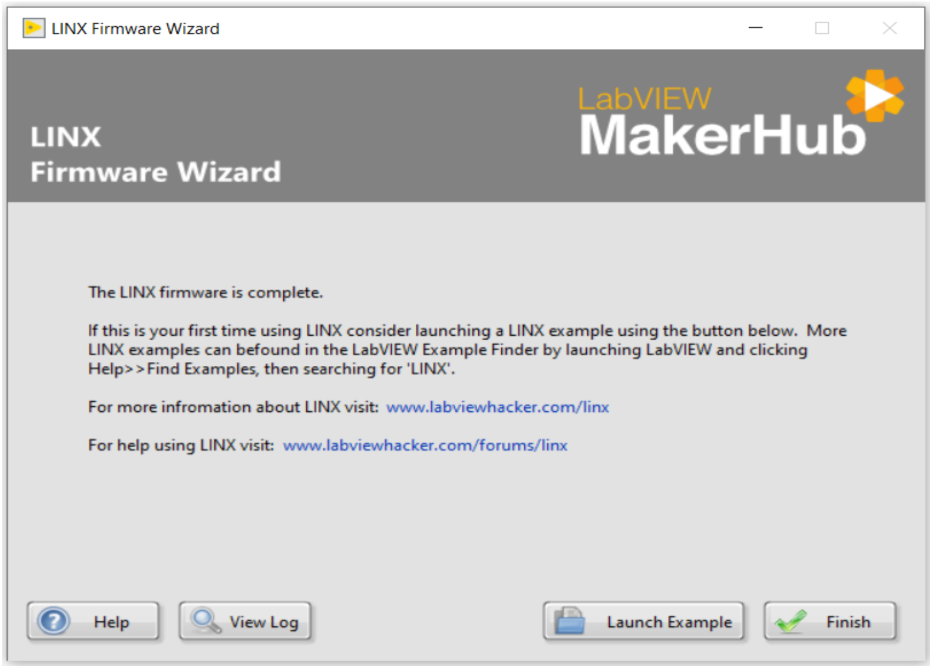
Step 4: Choose Upload type and set it as 'Pre-Built Firmware'



The following screenshot appears:



After the uploading is done, the LINX Firmware is now complete.



2.2.4. Differences between LIFA and LINX

At the time LIFA was released, it was designed specifically for use with the Arduino Uno although some modifications were made later to integrate Arduino Mega and other boards.

LINX is the successor to LIFA but is a completely new toolkit built from the ground up. LINX is designed to be a more generic hardware abstraction layer for embedded devices such as chipKIT, Arduino, myRIO, etc., rather than designed for one specific microcontroller platform. This means that LINX provides the infrastructure to add support for virtually any device.

In addition, LINX provides many improvements over LIFA such as better error handling, more sensor support, Ethernet and Wifi support.

LINX is therefore more suitable for virtual instrumentation compared to LIFA.

- **Proposed VI for the virtual oscilloscope**

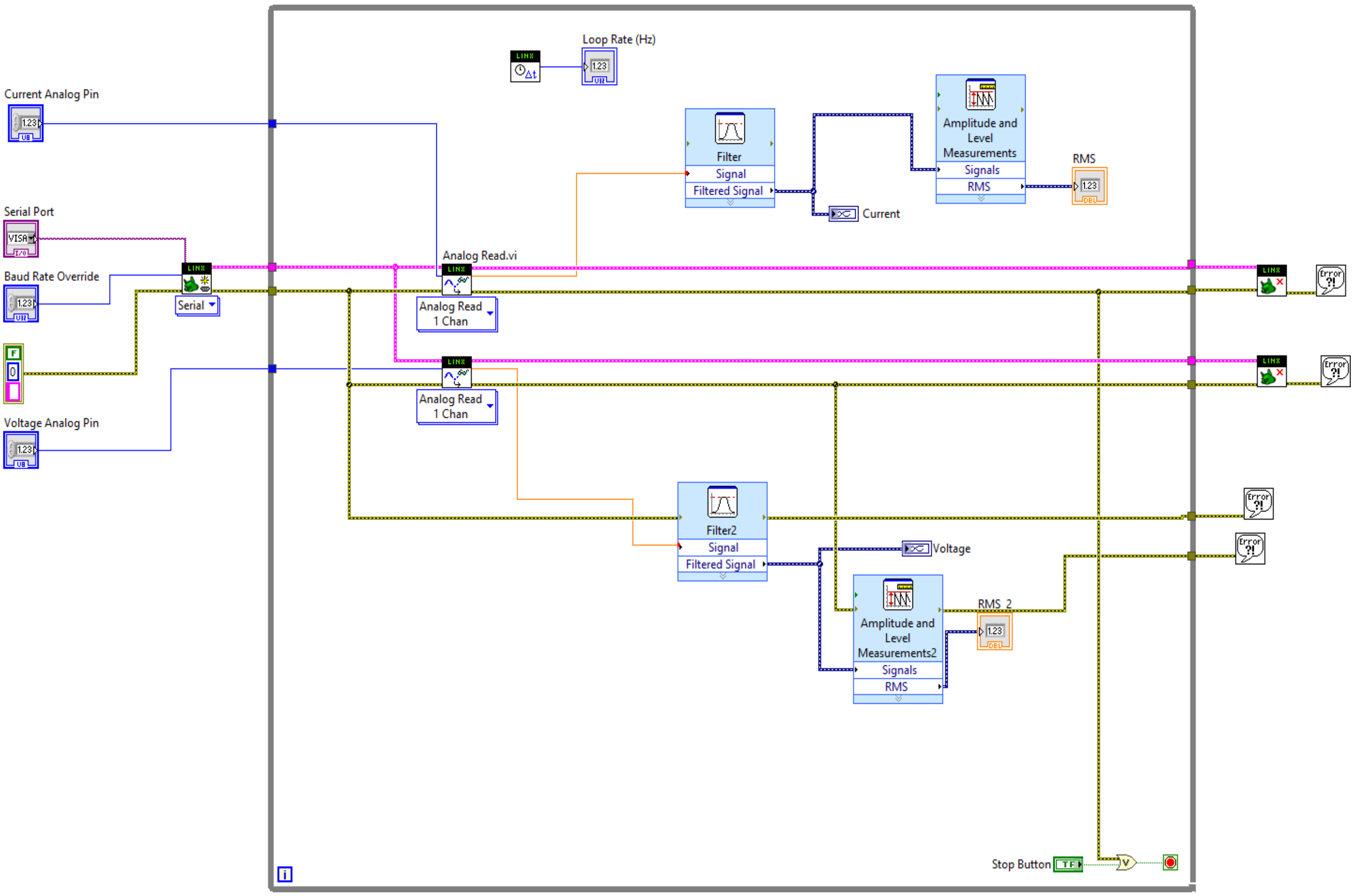


Figure 2.5: Block diagram of VI

The different blocks used are presented as follows:

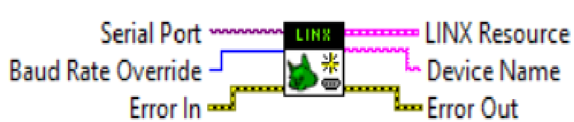


Figure 2.6: LINX Open

This block is used to open a serial connection to a remote LINX device. In our case the device used is Arduino Uno board.

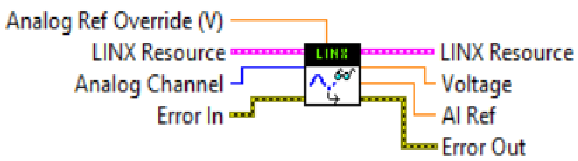


Figure 2.7: Analog Read

This block reads the value of the specified analog input channel (s).

Figure 2.8: LINX Close

This block is used to close the connection to the remote LINX device and free any local I/O resources.

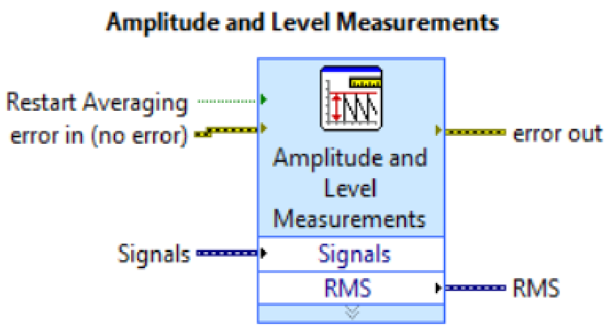


Figure 2.9: Amplitude and level measurement

It is used to perform voltage measurements on a signal.

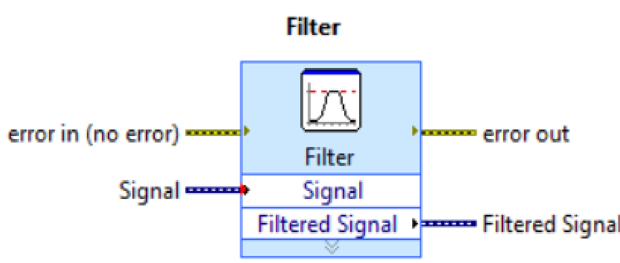


Figure 2.10: Filter

This block processes signals through filters and windows. For our case we used the Smoothing filter. The configuration is as shown in figure 2.11.

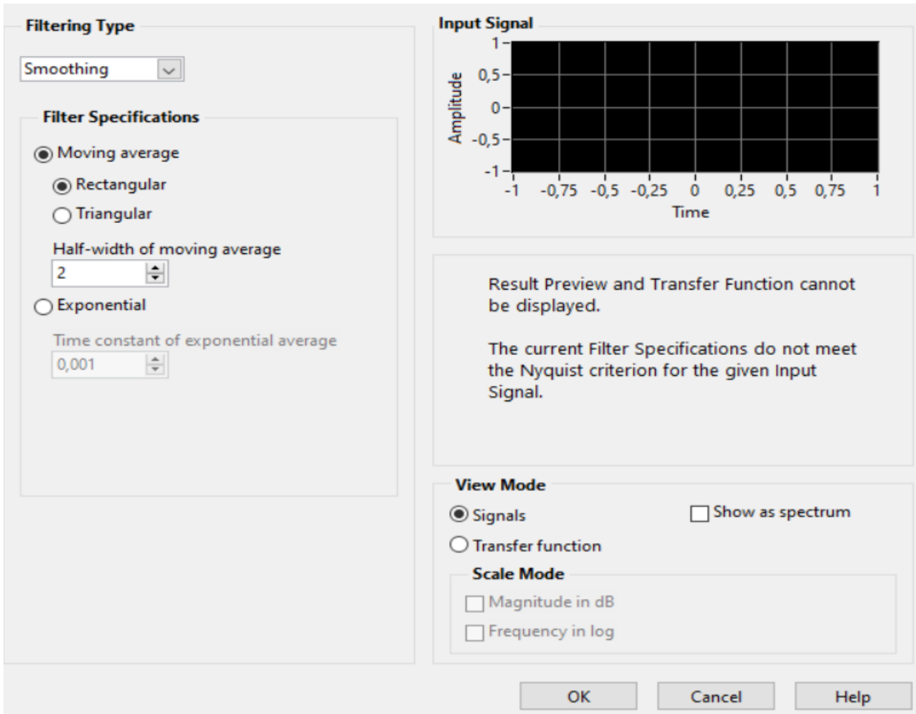


Figure 2.11: Configuration of smoothing filter

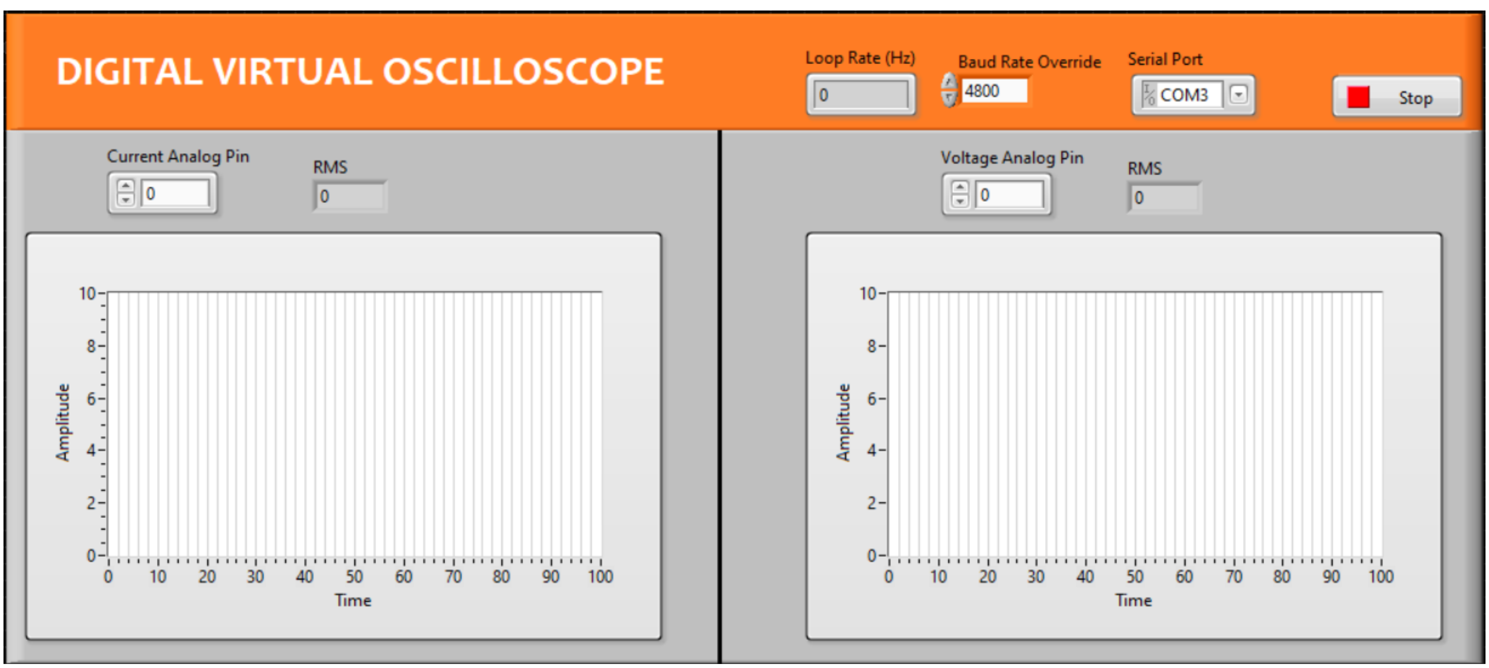


Figure 2.12: Front panel of VI

CHAPITRE 3: RESULTS AND DISCUSSION

Introduction

In this chapter, we present the different waveforms obtained by connecting the voltage and current sensors to DC and AC supply. First we present the results obtained when the two sensors are connected to the 5 V Arduino DC supply, followed by the result obtained when the voltage sensor is connected to the AC supply and lastly the waveform from the connection of the current in series with a 20 W lamp. A critical analysis of the different waveforms obtained is made.

The mounted prototype that enabled us acquire waveforms to be displayed on the PC is shown in Figure 3.1 below

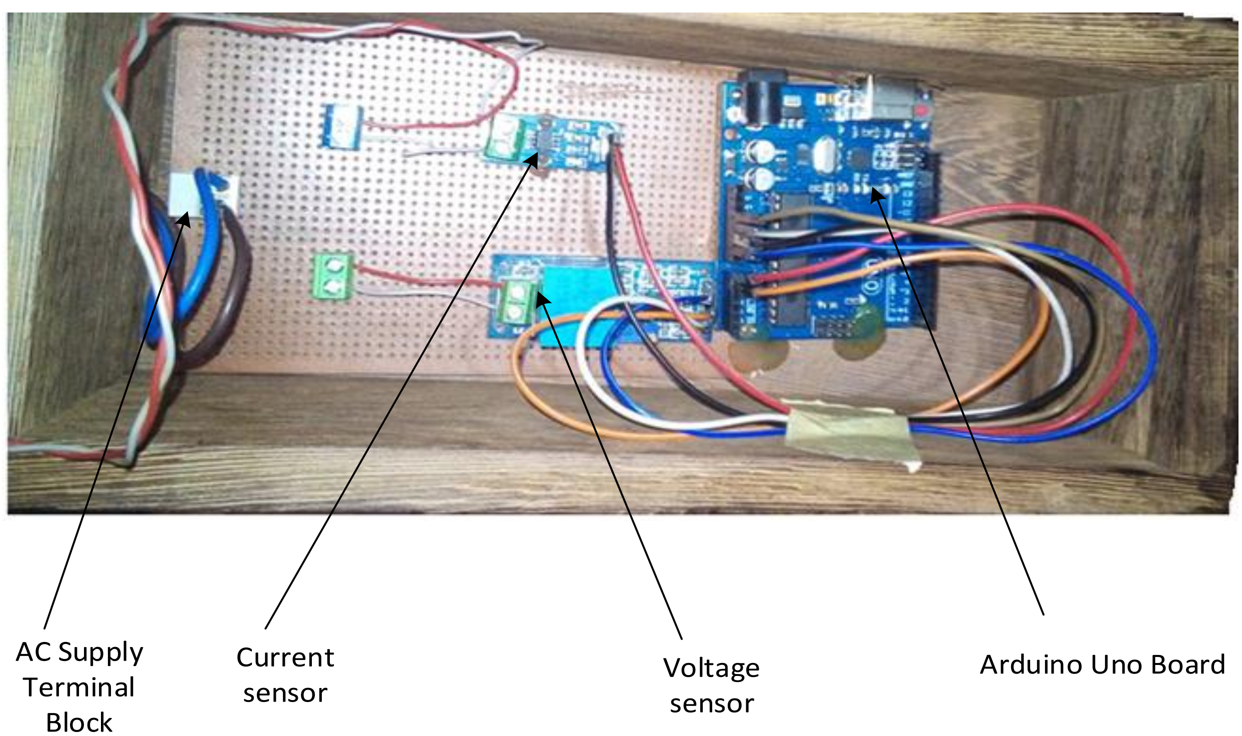


Figure 3.1: Mounted prototype for data acquisition system

3.1. Presentation of obtained results of the real-time virtual instrumentation

The following graphs in Figure 3.3 present the results obtained from real-time instrumentation with our digital oscilloscope. These graphs were obtained using the block diagram (VI) shown in Figure 3.2.

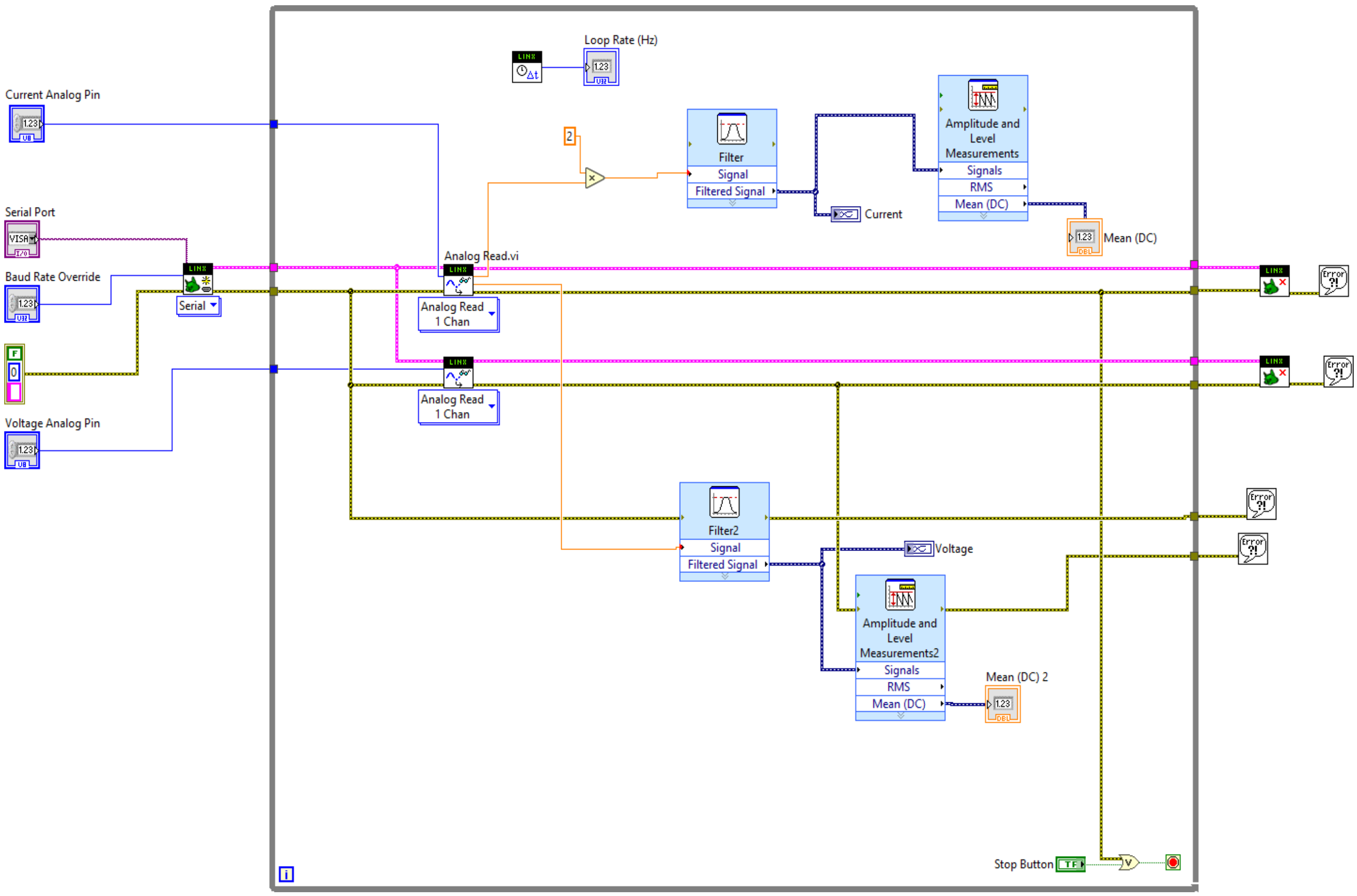
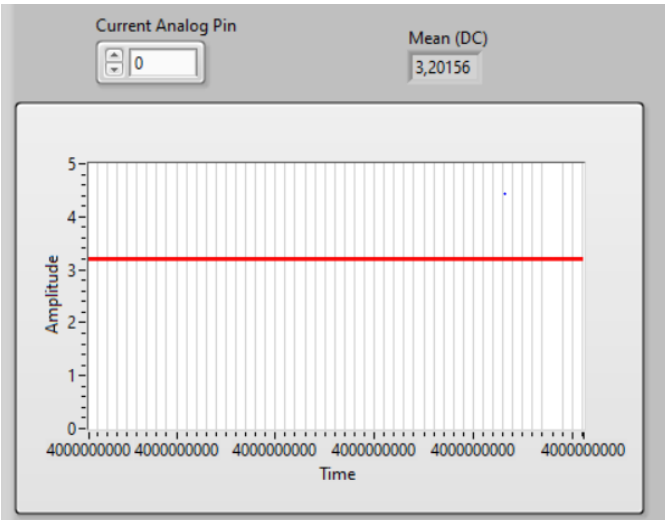
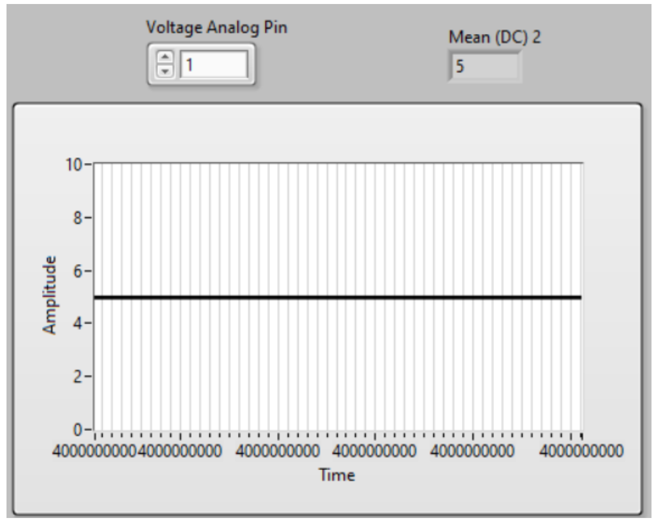


Figure 3.2: Block diagram for DC voltage waveform visualization





(a) (b)

Figure 3.3: Representation of Continuous Waveforms from DC Arduino Supply

(a) Current analog waveform, (b) DC Voltage analog waveform

The waveforms obtained show the DC voltage acquired from the Arduino supply. From the graphs we see that the analog signal acquired by the voltage and current sensors present a stable nature. The mean value of the voltage from the voltage sensor is the stable 5 V Arduino supply. So the virtual oscilloscope is thus effective in the visualization of Dc analog signals.

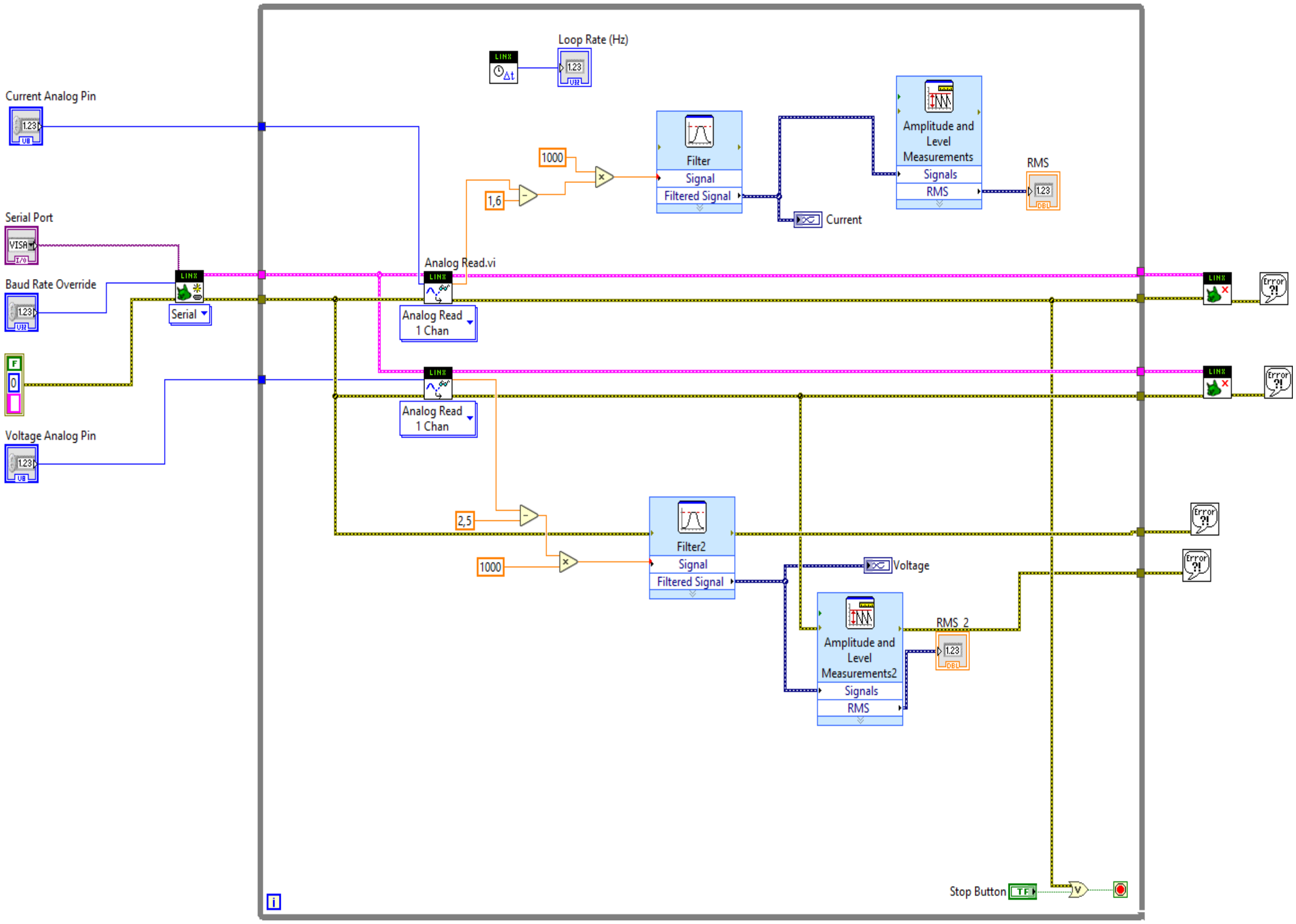


Figure 3.4: Block diagram for AC signals

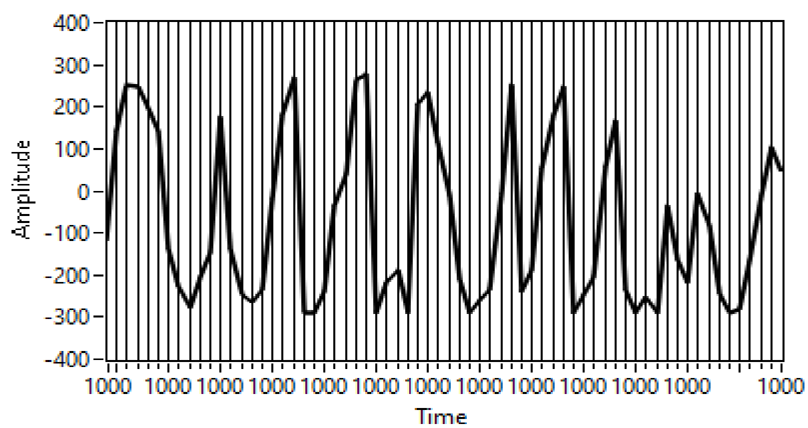


Figure 3.5: Waveform from voltage sensor connected to AC supply without filter

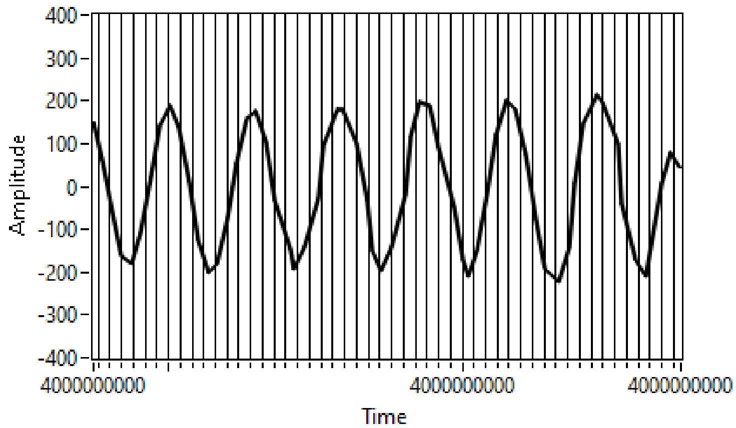


Figure 3.6: Waveform from voltage sensor connected to AC supply with filter

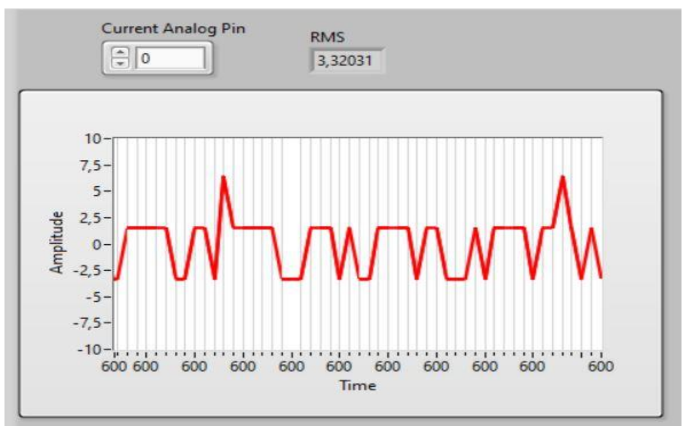


Figure 3.7: Waveform from current sensor connected to a 20 W electronic fluorescent lamp without filter

The block diagram presented on Figure 3.4 was used to obtain the waveforms in figures 3.5, 3.6 and 3.7. In the first scenario, the waveforms were obtained without filter (Figures 3.5 and 3.7). We can see the distorted nature of the AC voltage from the voltage sensor and the AC current from the current sensors. Figure 3.6 is an ameliorated nature of the analog waveform acquired by the voltage sensor. The filter is used in this case to attenuate the level of disturbance on the signal. We see in Figure 3.7 the raw signal obtained by the current sensor connected to a 20 W electronic fluorescent lamp. The addition of the filter block also helps to ameliorate the nature of this waveform (Figure 3.8).

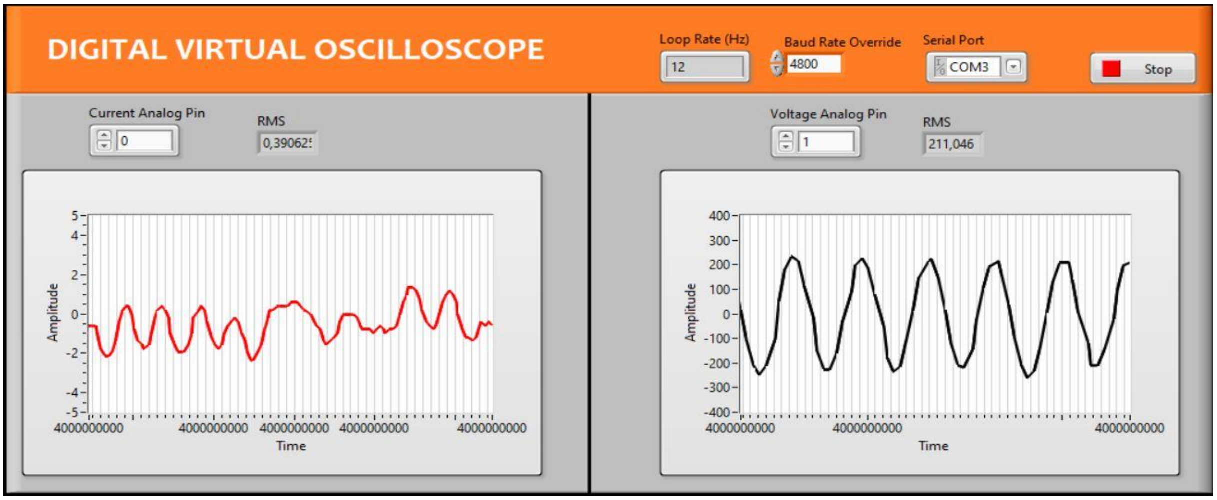


Figure 3.8: Waveform from current sensor connected to a 20 W electronic fluorescent lamp with filter (left) and waveform from voltage sensor connected to AC supply with filter (right)

The waveform shown on the left of Figure 3.8 is the ameliorated version of the AC analog signal derived from the current sensor. Despite the addition of the filter block, the signal still presents some level of distortion. It does not tend to a perfect sine wave. This is due to the effect of changing intensity produced by the lamp.

Again we see that the virtual oscilloscope is used to acquire AC analog signals and displays the nature of the waveform. The addition of the filter block helps to have an overview of what the expected waveform could be.

3.2. Cost estimate of deign virtual oscilloscope

Table 3.1: Cost Estimate of a 2-Channel Virtual Digital Oscilloscope

ITEM	QUANTITY	UNIT PRICE (FCFA)	TOTAL PRICE (FCFA)
Arduino Uno	01	8000	8000
Voltage sensor	01	5000	5000
Current sensor	01	5000	5000
Connector band	2	1000	2000
Terminal Block	04	500	2000
Wood work	-	-	5000
Cable	-	-	2000
Perforate plate	01	1000	1000
Programming of VI	-	50000	50000
Activation of LabVIEW	-	500000	500000
TOTAL			**580000**

From the cost estimate given in Table 3.1 above, we see that the cost of the designed virtual oscilloscope stands at **580 000 FCFA (five hundred and eighty thousand franc CFA)**. This cost can be relatively lower when the purchase and activation of the LabVIEW software is done collectively by a group of students or by an academic institution.

Conclusion

In this chapter, we have presented the results obtained from some tests we conducted with our virtual instrumentation device and also a simplified cost estimate for our device. We see that the virtual oscilloscope is used to acquire DC and AC analog signals and displaying their waveforms. In order to appreciate the nature of the waveforms of AC analog signals, we used filter blocks with predefined configurations. Worth noting is also the fact that we set baud rate of the Arduino Uno at 4800. This has enabled us to visualize stable waveforms.

GENERAL CONCLUSION

The objective of our work was to realize a virtual digital oscilloscope for the visualization of analog waveforms obtained from Arduino Uno board, voltage and current sensors. From the VI developed in LabVIEW software, we were able to effectively visualize and appreciate DC and AC analog signals. The virtual oscilloscope can therefore be used as an alternative to the real analog and digital oscilloscope. Some difficulties have been encountered, notably at the level of the speed of data acquisition of the Arduino Uno board. In order to ensure pertinent results, we used the appropriate baud rate from the Arduino Uno board and we added a filter in order to solve the problem of signal being slightly distorted. The virtual oscilloscope thus realized can be used as a device for practical instrumentation in order to enhance learning and the training of student teachers. It is no doubt that the virtual oscilloscope has a good practical value and wide application prospects.

In prospects, we hope to ameliorate the performance of the virtual oscilloscope by increasing the number of channel and using a better data acquisition board that can be used to acquire various analog signals. Given the fact that the device will be used by students for practical instrumentation, we also intend to connect PCs in the laboratory in a network such that the readings from the virtual oscilloscope can be shared from one PC to another.

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APPENDICES

APPENDIX 1: Flow diagram of data acquisition system