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Qscilloscope: A Pc-Based Real Time Oscilloscope

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ABSTRACT

The scenery of this paper is to design a PC- based Real Time Oscilloscope, called “Qscilloscope”. Qscilloscope is capable to connect a computer with a small device via universal serial bus (USB) port for voltage signal waveform display and alteration. It detects maximum +20V to minimum -20V with the input frequency range from 0.1Hz - 1 kHz. Furthermore, it interfaces with host PC via the USB port from 9.6k to 115.2k baud rate. Qscilloscope Software Application is constructed by using Visual Basic .Net for user to interface the device with a well designed Graphic User Interface. It consists of several embedded features such as open, save and print waveform. By changing the scaling properties and graphic properties, users are allowed to modify the input signal to a desired output waveform.

***Keywords**:* Analog Front End module, ARM Cortex M0 processor, LCD Display with touch panel, power supply

I. Introduction

Oscilloscope is acquainted as one of the most helpful instruments available for testing circuits. It is able to show the signals at different points in the circuit. One way to investigate an electronic system is to observe signals at the input and output and check the operating status of each system block. Traditionally, this instrument is hardware based on Cathode Ray Tube (CRT), designed to display voltage variations (periodic or otherwise). Yet they are expensive, bulky, and have difficulties on displaying low frequency waveforms. Qscilloscope endeavors to achieve the same functionality as a traditional oscilloscope. Besides that, it is using a Programmable Intelligent Computer (PIC) 18F Series microcontroller for data acquisition (including appropriate analogue circuitry) to digitize the analog input signal values and transfers the data to the Universal Serial Bus (USB) port (via USB D+/D- pins). A Microsoft Windows based software application will then display the waveform, as it would appear on a traditional CRT oscilloscope. As compared to several commercial products, Qscilloscope is not a new pc-based oscilloscope. Nevertheless, its software application has additional features by applying GUI advantages on displayed waveform, such as open, save and print features.In this paper, a general idea of Qscilloscope design is discussed in terms of hardware and software mechanisms. Deliberations of circuit design and microcontroller connections are discussed with presented figures. Additionally, a software program design is conversed to endorse the advantages of using a PC-based oscilloscope.

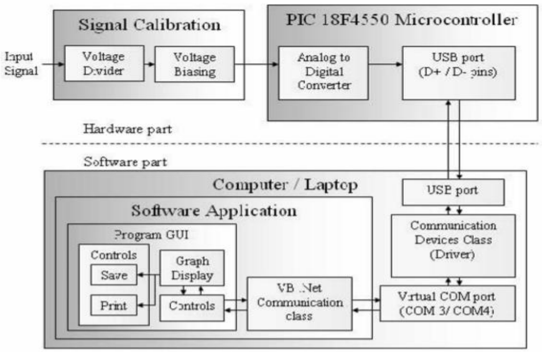


Fig 1 : Block Diagram of Qoscilloscope

1.1 An overview of Qoscilloscope:

This system is separated into two parts. Figure 1 shows the detail flows in each part. In part 1, an analogue signal is taken as input signal to the signal calibration circuit. After the calibration process, the signals are sent to the microcontroller for ADC operation. Then this analogue signal will be converted into digital form. The purpose of microcontroller is actually generating 4 kHz sampling frequency into ADC while receiving and transfer the digital data serially to the PC via USB connection. A straightforward programming code in .hexadecimal form is needed for the microcontroller to achieve the functions and receive controls from PC. In addition, the microcontroller performs a two ways communications between PC and itself.

Consequently, the digital data is received by PC, treated as an USB device input under a communication device class (class) driver. In the interim, a virtual serial com port is created as performing USB connection features. A software application is constructed to receive data from virtual serial com port as well as carry out control signals to microcontroller for ADC execution and etc. The received will be processed and displayed on the monitor screen under the graphic user interface of software application.

II. Hardware Design:

Firstly, the signal calibration circuit is proposed to include several op-amps for signal attenuation and phase shifting, in conjunction with potentiometers for calibration purpose. However, this propose requires the circuit to provide different voltage supply for different active components, such as ±12V for LM741 op-amp. As a result, Qscilloscope has to embrace with a voltage regulator to supply the specific range of voltage from 230V AC voltage supply, which is unable to get it from 5V USB voltage supply. Therefore, a voltage divider is introduced to this system design for portability and convenient. It is placed in the beginning of calibration circuit to control the input signal range. With the function of voltage divider, Qscilloscope is able to measure high voltage signal by attenuating the amplitude to a suitable range for signal digitization process.

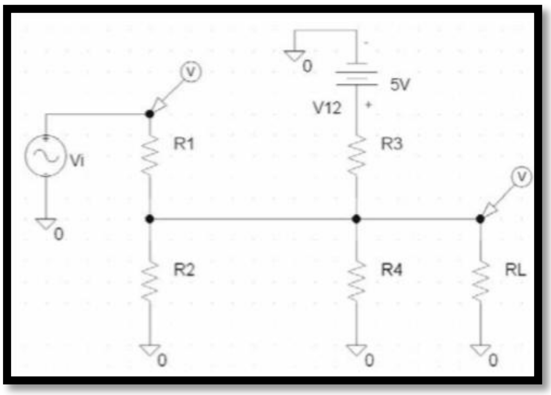


Fig 2: Voltage biasing technique

In Figure 2, a voltage biasing technique is placed after the voltage divider. By using superposition principle, the voltage across or the current through any resistor or source may be calculated by adding algebraically all the individual voltages or currents caused by the separate independent source acting alone, with all other independent voltage source replaced by short circuits and all other independent current source replaced by open circuits. Thus, input signal is attenuated and biased to a certain DC value (+5V) to achieve the entire input signal in positive range from 0V to 5V with respect to the requirement of ADC input range. Subsequently, a PIC 18F4550 microcontroller by Microchip Technology Incorporated is chosen to execute analog signal to digital signal conversion (ADC) on the output of signal calibration circuit. PIC 18F4550 comes with a low-power; 32Kbytes of flash program memory, 256 data erasable read only memory (EEPROM), 35 input/ output pins and built in 13 ADC channels, with pin connections as shown in Figure 3.

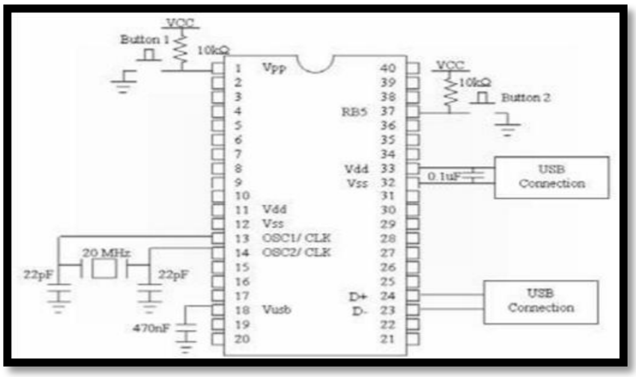


Fig 3: PIC 18F4550 pin connection with USB Boot-Loader.

This microcontroller is compatible with C compiler optimized architecture with optional extended instruction set. The microcontroller is programmed using an USB boot- loader with a life cycle of about 10000 times write/erase cycle for flash program memory and over 1 million erase/write cycle data for EEPROM data memory typical. Moreover, it has 10 bits built in ADC module with positive and negative voltage reference, submissive with programmable acquisition time. It has a well built Universal Serial Bus features with version 2.0 compliant, available for low-speed (1.5 Mb/s) and full-speed (12Mb/s) and requires a low voltage supply, +5V to operate as programmed. Ultimately, an all-encompassing hardware design is constructed as shown in Figure 4.

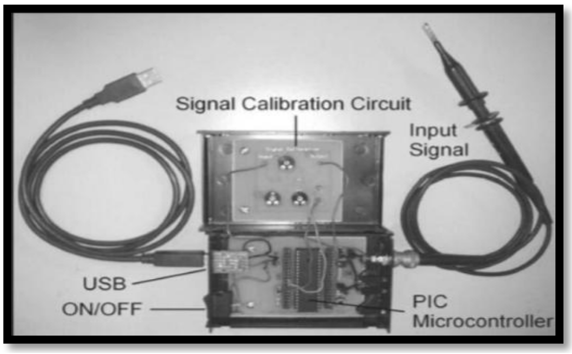


Fig 4: An all-encompassing hardware design

III. Software Design

3.1 *USB Communication*

3.1.1 USB Boot-Loader

An USB boot-loader firmware is used instead of a serial port communication to establish the connection between computer and microcontroller. This connection is built to program the microcontroller by loading a program .hex file into microcontroller, with a Windows based software application called PICDEM (TM) FS USB Demo Tool, provided by Microchip Technology Incorporated. The USB Boot-loader firmware is one of the easiest ways available for users to run in-circuit application upgrades via USB. User can easily switch the function of microcontroller to run as a boot-loader (programmable device) or an execution device. PICDEM (TM) FS USB Demo Tool is supplied (as well as a specific driver) to provide the necessary interface for programming purpose.

USB boot-loader firmware is a simple, black box approach and allows fast in circuit reprogramming of the device. It does not provide other communication capabilities rather than USB connection. It needs less than 2K byte for boot block usage (equivalent to microcontroller memory location from 0000 to 0800 in hexadecimal value). The further empty memory spaces (0801 to FFFF) will be used for microcontroller execution function. Moreover, a Windows driver is provided for the USB boot-loader firmware to identify an USB device. The PICDEM (TM) FS USB Demo Tool software comes with the USB boot-loader firmware package, under PDFSUSB folder. Initially, a microcontroller with empty program memory must be programmed with a "MCHPUSB.hex" file, under fw/Boot/_output folder in firmware package. This programming needs to use a simple serial port connection to program to allow the initial USB boot-loader codes stored in program memory 0000 to 0800.

Next, the microcontroller can be connected with the circuit and detected by PC using an USB cable. The USB driver is provided in the firmware package under Release Folder. After the device installation (using default Windows configuration), PICDEM will be able to detect an USB device and show in the drop down column with titled "PICDEM FS USB 0 (Boot)". Finally, users can read and erase the program memory in microcontroller, program the device with loaded .hex file and execute it via USB communication.

3.1.2 MPLAB IDE Programming

MPLAB Integrated Development Environment (IDE) is an integrated toolset for the development of embedded applications employing Microchip's PIC microcontrollers. Qscilloscope is using MPLAB IDE as a main microcontroller programming apparatus to generate execution files in terms of hex value (.hex file) for. Functions of microcontroller are written by MPLAB IDE in C programming language, in conjunction with Communication Device Class (CDC) firmware, compiled and assembled into .hex file. This file is programmed into PIC 18F4550 microcontroller using USB boot-loader. In addition, MPLAB has provided a well defined framework for PIC chips programming, yet this system is using USB boot-loader instead of program built-in simulator.

The CDC firmware is a migrating application to USB from RS-232 serial port with minimal impact on PC Software. In fact this firmware provides direct emulation of a serial port on PC running Windows 2000 and Windows XP. As the PIC18F4550 microcontroller is attached to the PC, a virtual serial COMx port is created. All PC software using a COM1- 4 port will work without modifications with the virtual COM port if only at a much higher speed (approximately 1Mbit/s).

This firmware requires 4K bytes of memory space. For any application running this firmware, driver is required to establish the virtual COMx port. In this design, CDC firmware source code is used as microcontroller program source code. This source code is written with some of the signal processing function, such as analog to digital conversion, digital value prototype for transmission and control signals to microcontroller for execution.

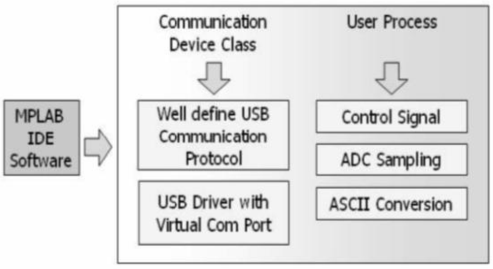

Communication Device Class
User Process
MPLAB IDE Software
Well define USB Communication Protocol
USB Driver with Virtual Com Port
Control Signal
ADC Sampling
ASCII Conversion

Fig 5: Diagram of MPLAB IDE Programming.

Figure 5 clearly describes the relationship between MPLAB IDE, CDC firmware and user process for ADC features. Initially, after the circuit is connected to PC via USB cable (with +5V voltage supply from USB port), the microcontroller checks whether the status of Pin 1. If the status is high, the microcontroller will run in USB boot- loader mode. Besides, if Pin 1 is grounded (low), the programmed .hex code will be executed according to the program design flow (As shown in Figure 3).

After the status checking, the microcontroller runs Initialize System function, for initializing the USB driver in PC. In this step, the microcontroller configures USB module in terms of speeds, transceiver selection, buffering mode selection, resistor selection and bus generation mode selection. Next, the function also initializes all I/O pin, including USART feature, Rx, Tx pins, and sets it to 48MHz (19200 baud rates).

Initialization step is followed by a looping function, consists of USB Task and User Process I/O functions. In USB Task function, microcontroller checks the USB bus condition in attach or detach mode, via pin 23 and 24 (D+/D-). If the condition is in detach mode, the microcontroller ends the whole program function as the USB voltage supply is disconnected. Next, internally, the function masks all the USB interrupt and unmasks the reset and idle interrupt listener for execution purpose. Meanwhile, the microcontroller checks the driver service interrupt and ready to execute respective handlers if any interrupt is occurred. At this step, microcontroller is standby to execute any transaction between device and PC via USB connection.

User Process I/O contains all the function defined by user. In this system, an ADC process and USB data transmission control is added. Initially, the microcontroller checks the bus status and triggers pin 19 and 20, to show a busy status on USB transmission by blinking two LEDs. If the bus status is not busy, the microcontroller checks the „start□ variable status. If the variable is triggered (after ADC operation is opened), ADC operation is executed concurrently by read the value on respective channel, else, the microcontroller compares the input buffer with control signal in ASCII character. So, if the comparison result is true, the microcontroller triggers the ADC process into „start□ stage, opens a new ADC operation and the process is looped to USB Task function to start the ADC operation.

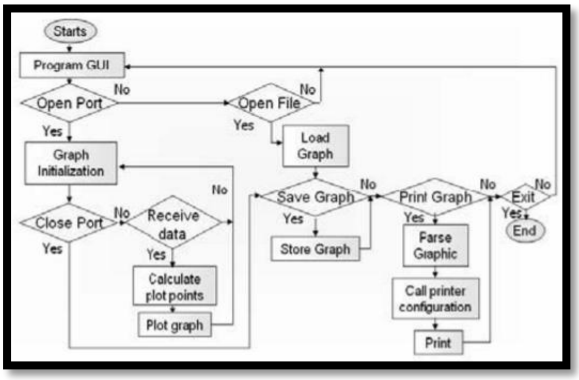


Fig 6: General Flow Diagram of Qscilloscope Software Application.

In ADC operation, microcontroller reads an analogue value from channel 1 (AN0), converts it into 10 bits digital value. This digital value is stored as an integer value in microcontroller internally. Hence, the microcontroller changes this integer value into ASCII character form, and transmits to PC via USB connection. In a nutshell, this process is running continuously until the next appropriate input control signal is detected in the input buffer. It controls the microcontroller for changing the sampling rate or closing the ADC operation.

B. Software Application Graphic User Interface

By using Visual Basic, I/O peripheral class and GUI class from VB.Net firmware are well defined and easily to be embedded into Qscilloscope software application. Hence, a proper program flow is generated as shown in Figure 6. Once the program execution file is launched, a program user interface in Windows form is created with title "QSCILLOSCOPE – DEMO VERSION" as shown in Figure 7. This program consists of menu strips, graph, combo boxes, track bars, status bar and common used Windows buttons. The application initiates by displaying this program user interface, while waiting for the user to command the program to the next instruction. User can either choose to open a data file (view a saved waveform), or directly display an incoming signal waveform from USB port.

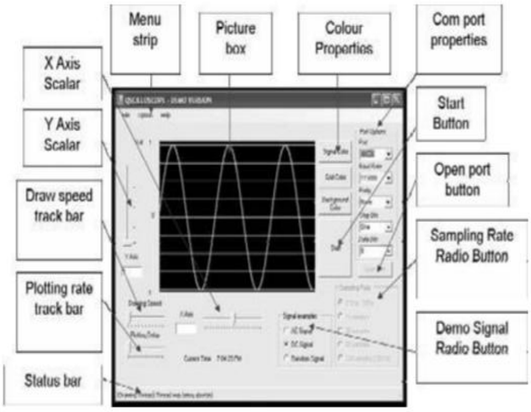


Fig 7: Qscilloscope Software Application Graphic User Interface.

On the right hand side of the Windows GUI in Figure 7, an appropriate com port setting (by default is Com3/4, 115000 baud rate, none parity bit, one stop bit and 8 data bits) is pre- selected. Open port button is clicked to set up connection and once it is established, the start button will be enabled. At the same time, the graph will initiate the signal in 0V. Next, the start button is clicked to initiates ADC operation on microcontroller. The program will listen to the incoming signal via virtual com port and plot the waveform after calculation with respective scalars. By adjusting the X-Y Axis, Draw Speed and Plotting Rate track bars, user can acquire an ideal waveform with regard to voltage and time domain. Meanwhile, user can command to close the port after receive a desired signal waveform. Besides that, software button interface is designed to provide a proper communication between PC and microcontroller via port connection. Hence, while the ADC operation turn on, open/close port button is disabled to avoid user to disconnect accidentally.

At the same time as the signal is generating, the background, signal and grid line color can be changed to achieve appropriate waveform visualization. Subsequently, the displayed waveform can be stored in memory space for further data processing. Stored data can be used for data acquisition such as comparison process with other signals, generate a graph with different scaled of frequency range and so forth. User is able to save the waveform by selecting the save function from menu strip (File > Save or Ctrl + S) with desired file name and location to be saved. Next, click the save button and wait for a few second for the program to generate graphic in picture box into the saved file. For waveform printing feature, the print function in menu strip (File > Print or Ctrl + P) has to be clicked. A print preview dialog box will appear with a waveform diagram to be printed. Next, printer properties and desired print page layout are configured. Eventually, the waveform will be exported as a print document and printed.While the output of Qscilloscope can be displayed on monitor screen by using Visual Basic software application, it also can be connected and displayed on a projector that is control by the PC. Furthermore, Qscilloscope software application is upgradeable for any additional feature without the need for new hardware installation.

IV. Result And Discussion

This system is firstly simulated by using Visual Basic Debugger. A tested signal is generated by function generator, and then connected to PC by using USB connection, through the system hardware prototype. Figure 8 shows the system hardware prototype (a black box device) with USB cable and test probe.

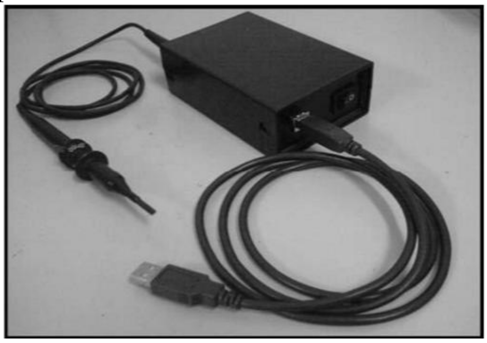
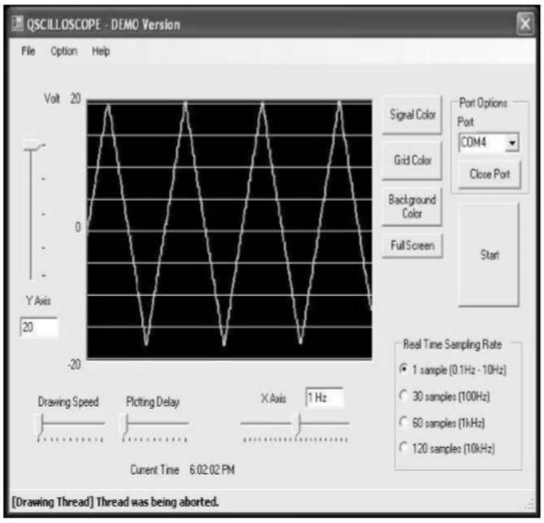


Fig 8: System Hardware Prototype

Simulation results show that the application is able to receive signal from 0.1 Hz to 1 kHz, as displayed on screen in Figure 9 and 10. The displayed signal is previewed in real time, with less than one second response to the detected input signal. Compare to the conventional oscilloscope, Qscilloscope is able to detect low frequency, whereas the conventional type is displaying the low frequency signal (0.1 Hz to 10 Hz) with a moving light dot.



QSCILLOSCOPE - DEMO Version

Port: COM4

Y Axis: 20

X Axis: 1 Hz

Real Time Sampling Rate: ● 1 sample (0.1Hz - 10Hz) ○ 30 samples (100Hz) ○ 60 samples (1kHz) ○ 120 samples (10kHz)

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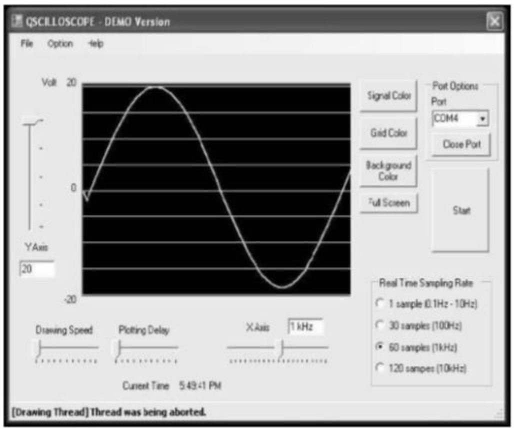
Fig 9: Reading 40V Peak to Peak Voltage, 1 Hz Triangle Signal by using Qscilloscope Software Application.



QSCILLOSCOPE - DEMO Version

Port: COM4

Y Axis: 20

X Axis: 1 kHz

Real Time Sampling Rate: ○ 1 sample (0.1Hz - 10Hz) ○ 30 samples (100Hz) ● 60 samples (1kHz) ○ 120 samples (10kHz)

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Fig 10: Reading 40V Peak to Peak Voltage, 1 kHz Sinusoidal Signal by using Qscilloscope Software Application

The sampling frequency is approximately 5 Hz for 0.1 Hz to 1 Hz signal and 4 kHz for 10 Hz to 1 kHz signal. For frequency range from 0.1 Hz to 10 Hz, the signal is able to be displayed as the sampling value is obtained. However, for frequency range from 10 Hz to 1 kHz, the signal is read by using 30, 60, 120 samples correspondingly to sample and hold a portion of input signal values, to be displayed in the graph. Therefore, delays on displaying graph are occurred, yet the graph is still adequate to be viewed as in real time response.

Besides that, there is a storage limitation to save sampling values in microcontroller, in order to obtain more precise reading. Higher oscillator components probably can be replaced in system hardware design to increase the capability of signal detection. In addition, by taking the advantage of GUI, the color properties of displayed graph can be changed, signal can be viewed in full screen mode, saved, and printed.

V. Conclusion

Qscilloscope involves various applications in electronics engineering. It is constructed base on basic electronics circuit design, microcontroller programming and Visual Basic software application programming. In line with the limitation of input range, this oscilloscope is designed for educational purpose.

Comparison to the conventional oscilloscope, the Qscilloscope is a low cost, portable and convenient device. Undeniable, the privilege of connection via USB port is kept pace with the advance technology of nowadays. Therefore, the oscilloscope waveform signal can be displayed on a larger screen for presentation purpose. User can save the displayed waveform and print it out for documentation.

However, the software application is restraint from displaying high frequency signal due to the low sampling frequency in hardware design. Consequently, a well constructed programming code in different type of microcontrollers is possible to increase the sampling rate for higher frequency reading. Besides that, the hardware design is unable to differentiate AC and DC value of displayed signal. Hence, further modification on circuit design should be emphasized to plot AC and DC signals separately.

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