Instrumentation Oscilloscope

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Abstract— Oscilloscopes are the devices used to observe varying signal voltages. Originally, the oscilloscopes are considered as costly, bulky and standalone devices. This project aims at building a low cost, handheld and portable oscilloscope with the basic utilities for efficient laboratory usage especially for instrumentation sensor measurement. It can be powered either using a 5V AA battery or the Kinetis FRDM KL25Z MCU's inherent USB power port. Thus, it will be designed to be used as a plug and play shield for the Kinetis L series Microcontrollers. The project has sampling as the basic technical basis and the various circuits being used to ensure that the errors introduced in the system are minimal. This device can be powered either using an AA/Li Ion 5V battery or Kinetis MCU's inherent USB power port. An additional circuit has the basic function to clamp the negative voltages within 0 – 3 V. The A/D converter in the MCU converts the signal to its equivalent digital values, which is calibrated in the software before being displayed real time using the SPI Communication. The LCD Display is used to portray the signal and display the respective frequency and amplitude values. The primary aim of the project was successfully and satisfactorily achieved.

Keywords—Oscilloscope; Instrumentation; Low cost; ADC; Kinetis KL25Z;

I. INTRODUCTION

An oscilloscope is a type of electronic test instrument that allows observation of constantly varying signal voltages, usually as a two- dimensional graph of one or more electrical potential differences using the vertical or y-axis, plotted as a function of time (horizontal or x-axis). This allows the measurement of peak-to-peak voltage of a waveform, the frequency of periodic signals. Oscilloscopes are used in the sciences, medicine, engineering, and telecommunications industry. General-purpose instruments are used for maintenance of electronic equipment and laboratory work. Originally, the oscilloscopes are considered as high cost, bulky and standalone devices.

The instrumentation oscilloscope has been developed for the users, primarily targeting the various college level laboratories and students. The signal usually encountered in experiments especially from instrumentation labs are primarily the low frequency signals and weak signals. The basic implementation of the idea is displaying the signal clearly on the LCD along with the peak to peak amplitude value and frequency of the signal. The device prototyped is a low cost, handheld and portable device which will measure the commonly used laboratory sensors efficiently. It is a simple solution to facilitate easy availability and less expenditure on oscilloscopes.

This device can be powered either using an AA/Li-Ion 5 V batteries or Kinetis FRDM KL25Z MCU's inherent USB power port. Thus, it is designed as a shield for Kinetis. It consists primarily of three parts, viz. Signal Conditioning, Power Management and Microcontroller Unit with integrated LCD Display. Input is taken through simple probes and fed to signal conditioning circuitry, which is then passed on Microcontroller unit which further processes and calibrates the data to be displayed on LCD Display as shown in *Figure 1*. The primary aim of the project is reduction in the cost and size of the oscilloscopes used in the laboratories by replacing them with a low cost and portable device. Thus with the theme of coming up with a low cost and portable substitute of the present day oscilloscope, this project was started.

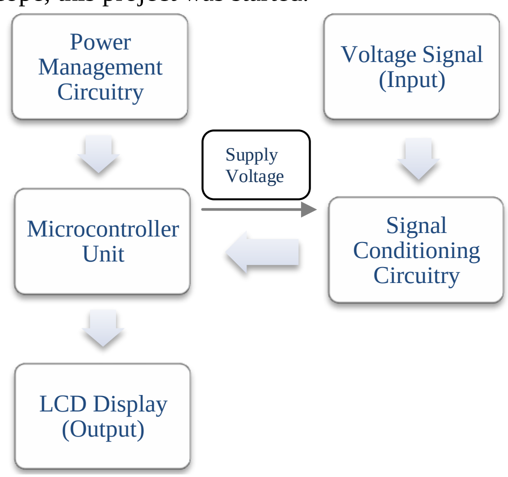

Figure 1- Top Level Block Diagram of the device

The originality of the project lies in its highlight point which is that the device is based on the basic implementation of circuits studied at the undergraduate level. It is simpler form of today's DSO with a few reduced features which are not used at the primary level of study.

The next section further explores the proposed solution and its hardware as well as software implementation in detail. Finally, the last section explains the results and conclusions of this project along with required appendix and references.

II. PROPOSED SOLUTION

The device proposed and prototyped is a low cost, handheld and portable device which will measure the commonly used laboratory sensors efficiently. It is a simple solution to facilitate easy availability and less expenditure on oscilloscopes. This device can be powered either using an AA/Li-Ion 5 V batteries or FRDM KL25Z MCU's inherent USB power port. Thus, it is designed as a shield for Kinetis. It consists primarily of three parts, viz. Signal Conditioning, Power Management and Microcontroller Unit with integrated LCD Display.

The device contains a *Battery Case with a Battery* to power the microcontroller efficiently. The microcontroller further provides the required supply voltage to other clamping circuit.

In the process to extract the desired signal, following the *Figure 1*, after its acquisition through simple probe, it is first passed through a *clamper circuit* which clamps any negative signals within 0-3 V.

Next this signal is passed to the *microcontroller* in which the signal is fed for further processing. The signal is first sent to the A/D converter, which converts the signal to its equivalent digital values, which is calibrated in the software before being displayed real time using the software module.

The sampling speed of the A/D converter is set ten times the maximum frequency signal such that the signal can be satisfactorily reconstructed without any distortion (at least *twice* the maximum frequency of signal), as given by *Nyquist rate* [2].The sampling speed is fast enough to get an approximate signal up to the frequency of 1 KHz. It has been chosen so that the device gets enough number of samples per time period of the input signal to satisfactorily reconstruct the signal. The Microcontroller Unit is programmed using specific algorithms (see source code) to collect data and pass it onto the ADC for sampling, once sampled it sends data to the *LCD Display (Output)* which displays the desired signal with its amplitude and frequency measurements.

Specifications of the proposed device are:
Voltage Measurement: -3.3V to 3.3V
Frequency Measurement: 0 - 1 KHz

III IMPLEMENTATION

Hardware and *Software* used for implementation and prototyping of the device:

Freescale Kinetis FRDM KL25Z - Microcontroller Unit
Nokia LCD 5110 – Low Power LCD Display
Resistors – 1K, 4.7k Ohm
mbed.org Online Compiler : Developing the source code
Eagle: PCB and Schematic designing
Circuit Labs: Simulation of various circuits

A. Hardware Implementation

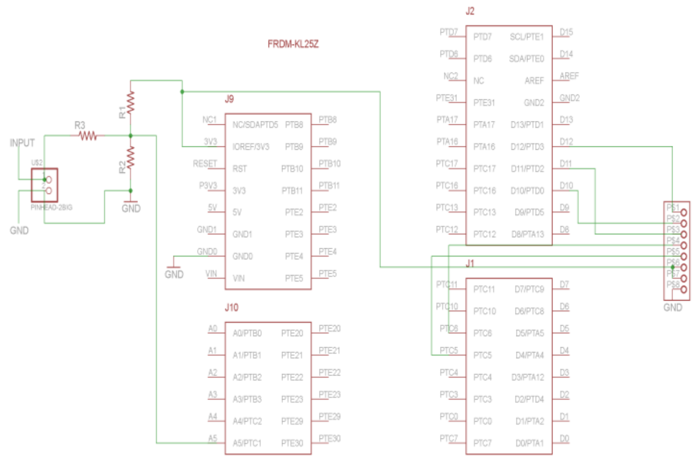

Figure 2

Figure 2 shows a schematic of the Instrumentation Oscilloscope (IOS). A resistor network shifts the level of the analog signal (within 0-3 V) as analog to digital conversion recognizes only positive data. KL25Z has an internal A/D converter which is used in processing the analog to digital data, thus, calculating the peak to peak amplitude value and the frequency of the analog signal. The acquired and conditioned signal is applied at analog pin A5of the Kinetis. The KL25Z is connected with the very popular 84*48 pixels Nokia 5110 LCD Display to display the output. It is a very low power, monochrome LCD Display. Moreover, it's very cheap, easily available and requires a very low driving current. The display communicates with the KL25Z using SPI (Serial Peripheral Interface) Communication. The device is powered either from a 5V battery or using KL25Z's inherent USB power. Common Ground is provided for the entire circuit using GND terminal of KL25Z.

The appropriate pin-mapping is used with LCD Display for SPI communication.

Pin-Mapping for SPI Communication:
SCK (Serial Clock) – PTC5
CS (Chip Select) – PTD0
DNK (MOSI) – PTC6
D/C (Data Write) – PTD2
RST (Reset)-PTD3

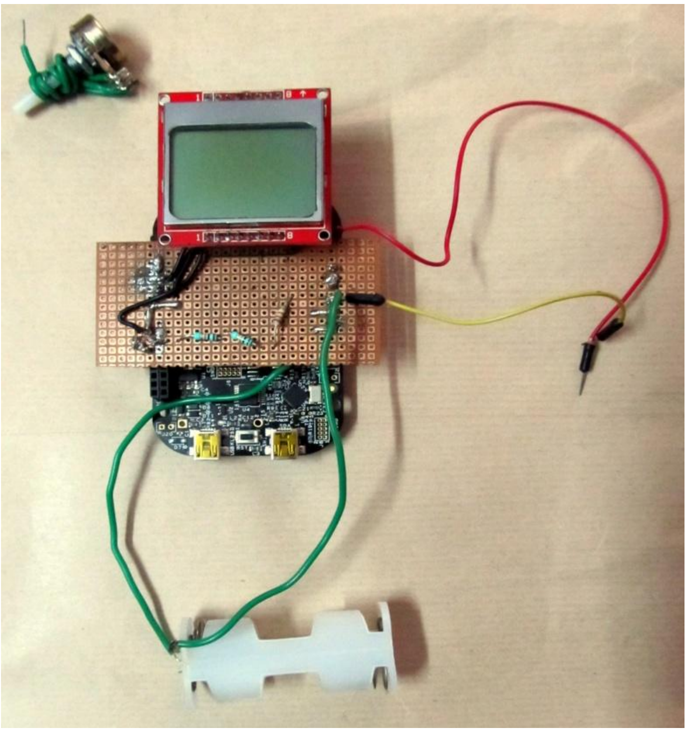

Figure 3 – Final Product Hardware

The final product can be seen in *Figure 3*, it is a home-made soldered general PCB. This PCB was designed in Eagle CAD (see Appendix A). The product can be easily mounted on the Kinetis KL25Z to work as a shield.

B. Software Implementation

The software for the device is implemented using the mbed.org online compiler. It uses Nokia 5110 library for PCD8544 drivers. The source code for the product is provided with the project.
The Kinetis communicates and displays the output on the LCD Display using the SPI communication.
Algorithm in a Nutshell
1. Sampling of data using KL25Z ADC (10 Samples per Time Period).
2. Scaling and data interpolation for accurate and easily understandable output.
3. Data display using LCD Display which uses SPI Communication.
Pseudo Code:

```
Include mbed Library
Include Nokia 5110 Library

def function drawLine()
def function markpixel(int ,int )
def function floatToString(char * , float , byte , byte )
def function adc()
def function interpolate(int ,int )

LcdPins myLcdPins = { PTC6, NC, PTC5, PTD2, PTD0, PTD3 }
NokiaLcd myLcd( myLcdPins ); // SPI is started here (8-bits, mode 1)

def function main()
  CALL LcdInitialise()
  CALL LcdClear()

while(True)
 initialize rem=0
 FOR rem<5
  set  sensorValue = adc()
  rem=rem+1
 ENDFOR
 set sensorValue=CALL adc()
 initialize cnt=0
 initialize tst=0;
 set  v1 = sensorValue * (2.5 / 1023.0)
 set  Max = v1
 WHILE tst!=5
  set  sensorValue =adc()
  set voltage equals to the sensorValue * (2.5 / 1023.0)
  IF fabs(voltage-v1)>0.01999 THEN
   IF Max<voltage THEN
    set Max = voltage
   ENDIF
   Increment the cnt
  ELSE IF fabs(voltage-v1)<0.01999
   Increment the tst
  ELSE IF cnt==1000
   break
  ENDIF
 ENDWHILE
 IF cnt<3
  set freq = zero
 ELSE Cnt<1000
  set freq = 10000.0/cnt
 ENDIF
 Calculate average number, avg_no
 CALL floatToString (m,Max, 1, 0)
 IF freq>999
  IF freq!=10000
   CALL floatToString(f,freq/1000, 2, 0)
   CALL gotoXY(0,5)
   CALL LcdString(m)
   CALL LcdString ("mv")
   CALL LcdString (",")
   CALL LcdString(f)
   CALL LcdString ("k")
  ELSE
   CALL gotoXY(0,5)
   CALL LcdString(m)
   CALL LcdString ("mv")
```

```
   CALL LcdString (",")
   CALL LcdString("N/A")
  ELSE
   CALL floatToString(f,freq/1000, 2, 0)
   CALL gotoXY(0,5)
   CALL LcdString(m)
   CALL LcdString ("mv")
   CALL LcdString (",")
   CALL LcdString(f)
   CALL LcdString ("Hz")
 ENDIF
 CALL drawLine()
 FOR i <=83
  set voltage = 0
   FOR j<avg_no
    set sensorValue =adc()
    set voltage = voltage + sensorValue * (2.5 / 1023.0)
    Increment j by 1
   ENDFOR
  set voltage=voltage/avg_no
  set n=voltage/0.0625
  FOR clr<5
   CALL gotoXY(i,clr)
   IF clr!=2
    CALL LcdWrite (1,0x00)
   ELSE
    CALL LcdWrite (1,0x10)
   ENDIF
  ENDFOR
  According to n
   Calculate bank and n1
   CALL markpixel (n,bank)
  According to absolute difference (npr1-n1)
   According to value of bank and bankpr
    CALL interpolate()
    CALL LcdWrite(1,0xff)
  set npr1=n1
  set npr=n
  set bankpr=bank
 ENDFOR
```

Every character is displayed in a 5x8 matrix. Since, we have set the display controller to draw the data horizontally, this means that every byte of data is saved row after row and if the controller reaches the 84th byte of data it jumps to the next column.

The data is written into the controller's memory by using the (SPI Communication), i.e., **LcdWrite()** method.

Here the 1st parameter decides whether the passed data is a command for the controller or just data to be written into the memory (like a single character). After the DC pin is set to HIGH or LOW and the chip is enabled to receive data, the actual data transfer starts. The data is shifted bit by bit into the memory of the controller starting with the most significant bit (MSB). That means that the first bit (from left) is put into the memory first. This pixel will be passed bit after bit into the last column of the 5×8 matrix.

The function **LcdCharacter()** does exactly the same for every byte (row of data) for a defined ASCII character of the already mentioned array. It helps to display single character on the LCD at a time and function LcdString() prints complete string on the LCD using the **LcdCharacter()** and **LcdWrite()** functions. Function LcdString_anim() is exactly the same as LcdString() except that it has delay for providing animation while displaying character on the LCD.

The function **LcdInitialise()** sets pinmode of various LCD pins and executes various command for setting temperature coefficient, Vop etc for LCD to function properly and **LcdClear()** is called to clear the contents of the LCD.

Function **gotoXY()** has arguments, column number and row number, which indicates where cursor has to be positioned. **Drawline()** function is declared to draw the reference line for the waveform to be displayed on the LCD.

adc() method returns the value provided by the A/D converter provided on the launchpad which will provide a floating point number ranging from 0.0 to 1.0 and **markpixel ()** function position the cursor to the location where pixel is to be displayed according to the value returned by the adc () function which draws the waveform of a signal. Here, while plotting waveform, linear interpolation is done which is implemented with the help of **interpolate ()** function whose 1st argument is the previous value of pixel displayed and 2nd argument is the value of pixel that is going to be displayed.

For displaying peak value and frequency on the LCD, peak value and frequency are converted to string using **floatToString()** method.

In the **main ()** function, LcdInitialise() and LcdClear() are called and then a set of data is sent to controller of the LCD for display. Also, we have to set the reference voltage for the A/D conversion.

In the while loop, we have written instructions that we want to repeat continuously.

Here, we have calculated frequency and peak value. Frequency is calculated by 1st storing the 1st value provided by the adc() function in a variable and then comparing it with the next values provided by the adc() function till the same stored value is returned. Meanwhile, we count the number of values provided by the adc() function while the comparison is made. The value of the frequency and the peak value of the signal are calculated.

In the 2nd step, we calculate the average number using our specific algorithms (see source code) which is responsible for displaying the complete waveform on the LCD irrespective of the frequency. The minimum value of average number is 1 which displays maximum frequency, while the maximum value of average number is 100, which displays zero frequency.

In the 3rd step, first the reference line is drawn and the values of the amplitude and the frequency are displayed on the LCD and specific pixels are drawn using the algorithms discussed above. For More information refer to code in source code.

IV. RESULTS

The Instrumentation Oscilloscope was tested under various conditions and performance analysis was conducted with the acquired data.
The simulation results for the device are shown in *Figure 4*.

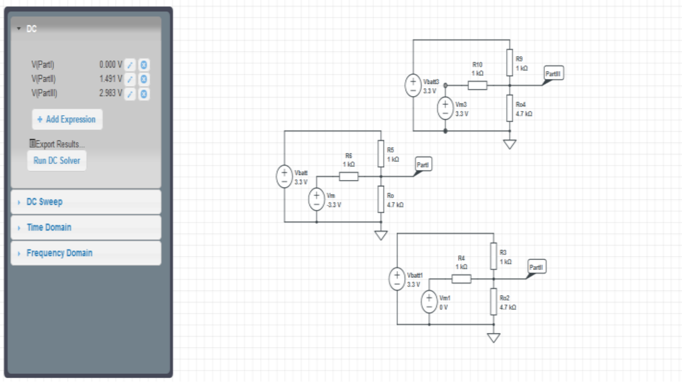

Figure 4

The device was tested for basic transducers such as potentiometers, photoresistors, etc. It gave appropriate and satisfactory results.

V. CONCLUSIONS

This low cost, low powered instrumentation oscilloscope can have significant usage for educational purposes, especially in the instrumentation.
It is an ideal solution for those looking for a quick and efficient analysis. This project aimed to find a low cost, portable substitute in place of conventional oscilloscopes. The primary aim of the project was successfully and satisfactorily achieved.
Currently, it has been tested with constant, square, triangular and sinusoidal variations, but it can similarly work for any other voltage form/variation as well.
The final performance *analysis/ specifications* found after software and hardware testing are:

- Maximum Frequency detected without any distortion: 1 KHz.
- Maximum Amplitude of Signal measured without any distortion: 3.3 V.
- Range: -3.3 V to 3.3 V.
- Waveforms observed successfully: DC; Triangular; Square; Sinusoidal;

Few of the strengths of the project are:

1. It is a handheld and portable device.
2. It's very low cost device (see Appendix B).
3. It covers almost all sensors with low frequency output response.
4. It can be easily mounted on FRDM KL25Z and can be used as a Plug n Play Shield.
5. The circuitry used is very simple and device is very easy to use.
6. It's easy to debug and can be easily further developed and programmable.

Future Scope of the Project:

1. The device currently doesn't store results. In future, it could be given an external memory or the results can be stored in the computing device used to power the launchpad using a GUI.
2. Sensors with high frequency response are currently not catered. This can be further improved in the next version.

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APPENDIX A

The PCB Design is made using Eagle CAD and is shown in *Figure 5*.

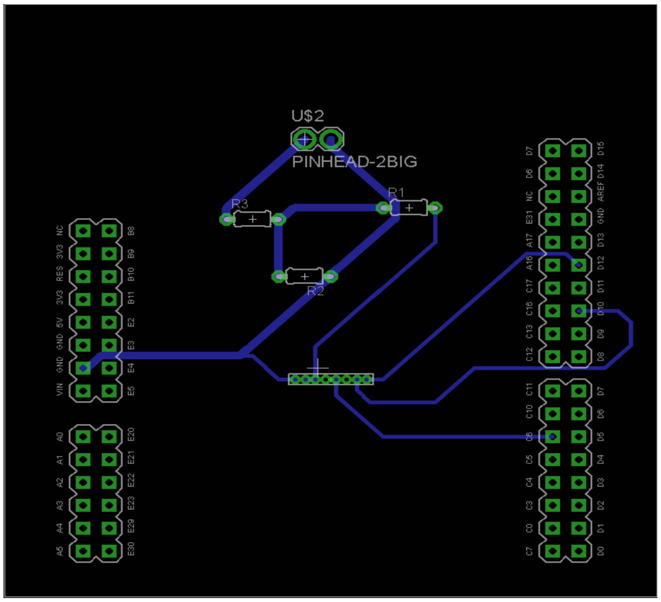

Figure 5 – PCB Design of IOS

APPENDIX B – BILL OF MATERIALS

Give a table which shows the name of the hardware/software component, number of components in the project, cost per component, total cost of the component, and the total cost of all components.

	Component	Manufacturer	Cost per component	Quantity	Total cost of component
1	Kinetis FRDM KL25Z	Freescale	13$	1	13$
2	Nokia 5110 LCD Breakout Board	-	10$	1	10$
5	Miscellaneous (Resistors, PCB,etc.)	-	4$	-	4$
	Total Cost of the Project				**27$**