



# DIGITAL STORAGE OSCILLOSCOPE & SPECTRUM ANALIZER

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**Abstract:-** This paper provides one possible solution for a low-cost oscilloscope. The oscilloscope is based on the dsPIC33f processor. It has a 128x64 graphic display, a touch-screen panel and an SD card slot.

**Key Words:** Oscilloscope, Spectrum Analyzer, Microcontroller

## 1. INTRODUCTION

With the rapid development of technology, the oscilloscopes of today are completely dominated by Digital Storage Oscilloscopes. These Oscilloscopes have wide bandwidth, ability to trigger on a variety of conditions, perform real-time DSP operations and ability to store the acquired data. Having a lot of advanced features, Digital Oscilloscopes are still expensive, or they depend on PCs. This paper presents a solution for a low-cost and simple standalone measuring device. It can be used as an oscilloscope or a spectrum analyzer.

## 2. DEVICE DESCRIPTION

The main idea of this solution is minimizing external circuitry. All digital oscilloscopes have the same structure: input stage, sampling circuit, A/D converter, buffer memory for the acquired signal, microprocessor, display memory, display, triggering circuit and control circuit<sup>[1]</sup>. Designing input circuitry is the most challenging task for oscilloscope designers, it's the critical point of all oscilloscopes and it consists of a compensated attenuator circuit and an amplifier circuit. For our device, universal amplifier circuits are used, because it's an oscilloscope for low speed signals. To simplify the design we decided to find a microcontroller that has enough RAM memory to buffer and display data. It also needs to have internal A/D converters with a minimum speed of 1MSPS, it must be low-cost and easy to find. After adopting these specifications and selecting the adequate components we designed the device.

The device consists of 6 main parts:

1. Input Stages
2. Microcontroller
3. Display
4. Keyboard
5. Touch Screen

6. SD Card slot

The block diagram of the device is shown in figure 1.

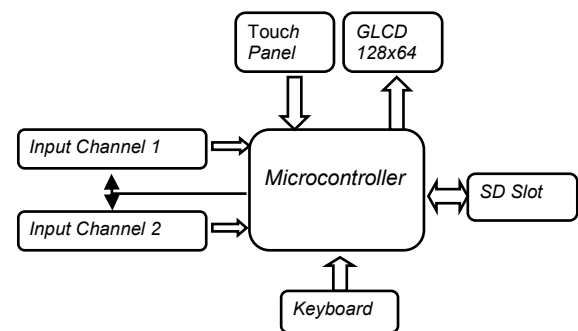


Figure 1. Diagram of device

### 2.1 Input stage

Oscilloscope probes are connected via BNC connectors. From there, the signal to be measured passes through several different stages, as it's shown in figure 2:

- 1) AC/DC coupling - it's implemented with a 100nF capacitor that can be by-passed by closing a relay.
- 2) 1/10 Attenuator - attenuation is achieved using a combined resistive and variable capacitive voltage divider. Its values are chosen so that they have total input impedance of 1MΩ and about 25pF capacitance, as these are common values for most commercially available oscilloscopes. Probe compensation is done by an adjustable 50pF trimmer capacitor. This stage is controlled by a relay.
- 3) Overvoltage protection – this stage protects other stages against voltages exceeding ±5V. It's consists of 2 reverse-biased Diodes in series with a current limiting resistor. Diodes are connected to the power supply lines +5V and -5V.
- 4) Input buffer – consists of a unity gain operational amplifier. This buffer isolates the device circuits and the measurement circuit. This amplifier must have at

least the following characteristics: Input and Output voltage range  $\pm 5V$ , bandwidth of at least 10Mhz, slew rate larger than 100V/us – the signal must be able to swing through the whole voltage range (-5V - +5V) during one sample period of 0.1us, low input bias current –to have the smallest possible influence on the measuring circuit. We decided to use Analog Devices AD8041<sup>[2]</sup> operational amplifier, as this amplifier fulfills the requirements.

- 5) Gain circuits – signal can be amplified using a multiplier of 2 or 5 or a combined multiplier of 10. This stage allows us to measure weaker signals with voltage ranges of ( $\pm 2.5V$ ,  $\pm 1V$  and  $\pm 0.5V$ ). Multiplier circuits are designed using operational amplifiers<sup>[2]</sup>. Operational amplifiers are connected in noninverting configurations. Requirements for the amplifiers are the same as it is for the buffer stage; therefore we used the same operational amplifiers. Gain is selected by 2 relays.
- 6) Adjusting circuit – This circuit adapts signals from  $\pm 5V$  range, to 0V–3.3V, which is the dsPIC A/D converter range. We need to implement this equation:

$$V_{out} = \frac{3.3V - 0V}{+5V - (-5V)} V_{in} + \frac{3.3V}{2} \quad (1)$$

It's done by using an operational amplifier and a 1.65V voltage reference. The operational amplifier attenuates the signal 3 times. Again, the same AD8041 amplifier is used. As a voltage reference we used a 1:2 voltage divider connected to +3.3V, in series with a buffer circuit.

For one input stage we needed 4 operational amplifiers, so we used AD8044, quad op-amp, to simplify the design. Relays are controlled by the microcontroller software, over a ULN2008 Darlington driver.

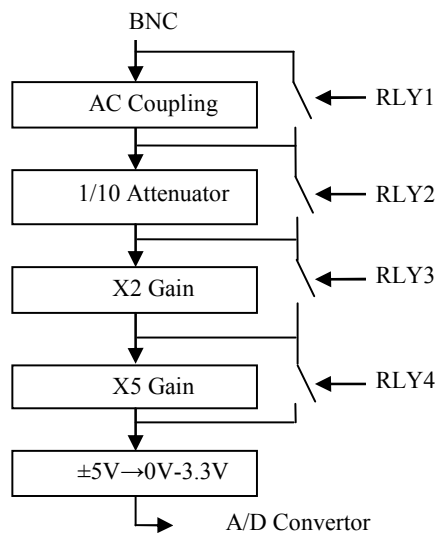


Figure 2. Diagram of 1 input stage

## 2.2. The microcontroller

The core of this device is the dsPIC33f256GP710<sup>[3]</sup> microcontroller, which has 2 integrated A/D converters, with a maximum sampling rate of 1.1Ms/s, thus the oscilloscope will incorporate 2 input channels. The internal Microcontroller memory allows buffering of up to 4000 samples. Its integrated DSP functions, give the ability to perform FFT, and to use the device as a spectrum analyzer, without additional hardware.

## 2.3 Interface

The results are being shown on a low-cost 128x64 graphic display. This display was a compromise between detailed presentation of the signal and the cost of the display. The communication between the display and the microcontroller is implemented by a parallel interface. All display lines are 5V compatible, and this could be a problem, because the microcontroller of choice is 3.3V compatible, but since the logical threshold of the display lines is 2.5V, and the input lines of the microcontroller are 5V tolerant, these two devices are connected directly.

There is a resistive touch panel attached to display. It's controlled by microcontroller with a simple circuit. It enables easy device control by the user. Reading coordinates from the touch panel is done by using additional multiplexed analog inputs of the microcontroller, so the panel is not being used while acquiring input signals.

The device contains an 8 button keyboard, with 2 buttons directly connected to the microcontroller pins, that have the ability of external interrupts, and these buttons are used during signal acquiring.

## 2.4 Storage

A great advantage of modern oscilloscopes over old analog ones is that they are capable of saving the acquired data on some kind of permanent memory. We decided to implement this possibility. For permanent memory we used a flash memory, namely an SD Card. The microcontroller communicates with the SD Card by using open SPI protocol. This is a serial type protocol that allows a high enough transfer rate. The SD card is 3.3V compatible, so it's connected directly to the microcontroller. All data are saved in files in FAT16 file system, which is implemented using the "Microchip MDD File System" library for dsPIC microcontrollers. The samples are saved in the internal ".osc" format.

## 2.5 Power Source

The device is powered by a DC adapter with the following characteristics: +9V, 0V and -9V. Two +9V batteries in series are also supported. The power supply circuitry uses voltage regulators for +5V, +3.3V and -5V.

## 2.6 Signal acquiring and processing

For acquiring the signal the integrated A/D converter is used. It is a SAR type of converter and it's capable of acquiring signals with a maximum sample rate of 1.1Mps. The resolution of the A/D converter is 10 bits,

which is more than enough for this device. In firmware we can change the conversion sample rate; there are 7 predefined sample rates: 1.1Msps, 500ksps, 100ksps, 50ksps, 10ksps, 1ksps and 100sps.

This microcontroller has an integrated DMA mechanism, which is very useful for real time measurements. This mechanism grants the A/D converter direct access, to predefined buffers in memory. There are 2 buffers with a maximum of 2kB of memory. While the A/D converter is filling one of these buffers with data, the microcontroller is processing data from the other buffer and it is controlling other parts of device.

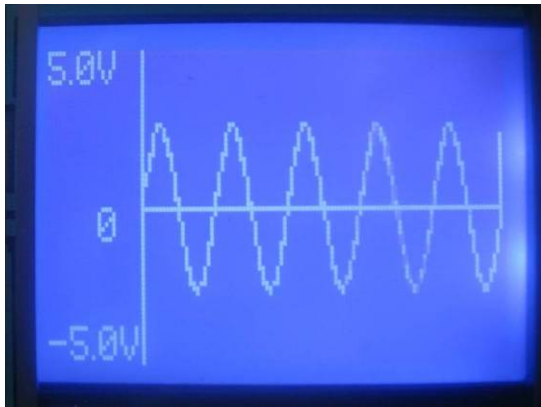


Figure 3. Oscilloscope display while acquiring 5kHz signal

One type of trigger control is implemented – a basic trigger on the rising or the falling edge, with the user selected level of triggering. It's done by firmware.

In figure 3. a photograph of a 5kHz sine signal is given.

The Spectrum analyzer is implemented by applying 512 FFT on the acquired signal. FFT is based on the radix-2 algorithm. Before using FFT, Hanning Window filter is applied, which lessens spectrum leak. After that, results are scaled, peak frequency is found and all that is presented on the display. A photograph of spectrum analysis of a 10 kHz and a 4kHz sine signal mix is shown in figure 4.

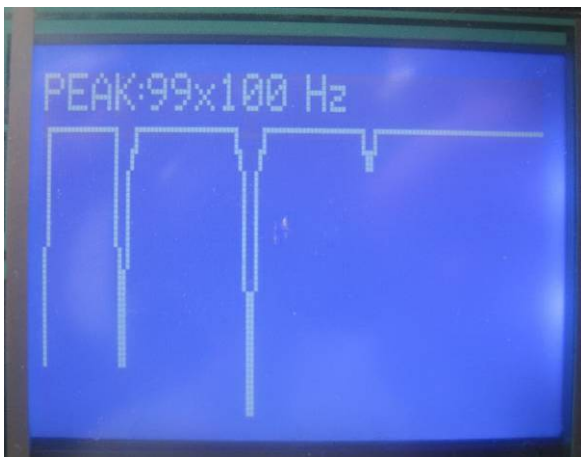


Figure 4. Spectrum analyzes of 10kHz+4kHz sine signal

Figure 5. shows a spectrum analysis of a 5kHz square signal.

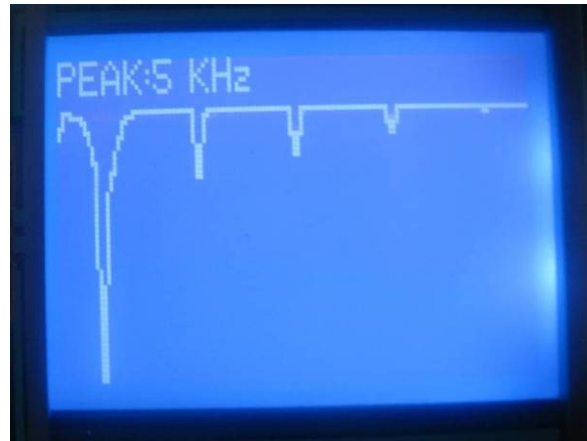


Figure 5. Spectrum analyzes of 5kHz square signal

For further analyzing the acquired signal in a spreadsheet software, a PC application is created, that converts data from “.osc” to “.csv” format (Comma Separated Values). In figure 6. a graph made by a spreadsheet application is shown.

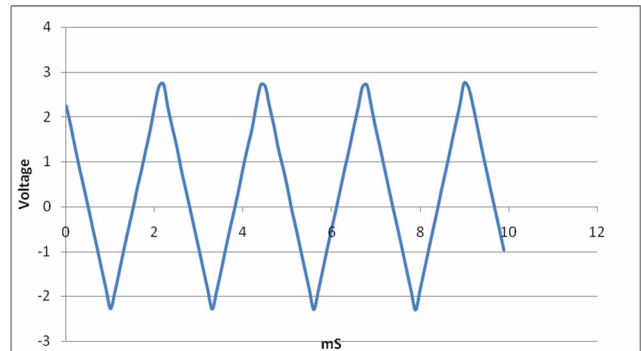


Figure 6. Saw signal converted to Excel

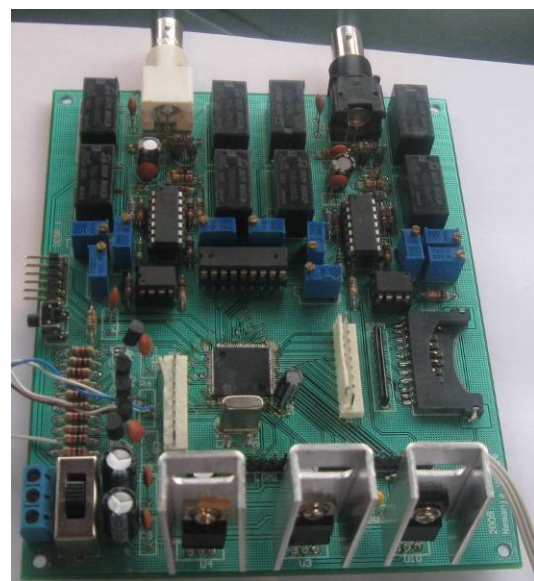


Figure 7. Device printed circuit board

A photo of the device prototype is shown in figure 8.



Figure 8. *Device prototype*

### 3. CONCLUSION

This paper analyzes one possible solution for low-cost oscilloscope. The details of its analog input stage, digital processing and visual presentation of the results are given. It is shown that such low-cost device can be built and it fulfills its expected characteristics.

Although the device can be used for its own purpose, there is still a lot of space for improvements. First of all, over an external port we can provide USB connection to PC. Using of external A/D converters would provide us to analyze signals of much greater frequencies. Also, with just improving the firmware, we could implement: “Equivalent time method” technique, digital filtering and advanced triggering techniques. This is not a final version of the device – it’s only the first step to the solution of the problem.

### ACKNOWLEDGEMENT

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### 4. REFERENCES

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