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Reconfigurable instruments for experiments in physics – the speed of sound measurement

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Abstract. This paper describes the applications of reconfigurable devices in scientific instruments and demonstrates the implementation of an instrument for measuring the speed of sound in the air. This is a simple and inexpensive instrument which is easy to use, portable and very useful for teaching physics.

1. Introduction

The measurement of the speed of sound in air is a classic experiment in introductory physics laboratory courses. Usually, the experiment is performed at room temperature with the standard instruments such as function generator and oscilloscope [1], or using a data acquisition connected via a computer [2]. Here, we describe an experiment for measuring the speed of sound in the air using the instruments implemented by the reconfigurable devices named FPGA. With the complete hardware kernel architecture, we can configure to match the necessary function specifications for various measurement environments and requirements [3, 4]. Here, we introduce a type of reconfigurable instrument design which use for experiments in classical physics. This is useful to design the inexpensive instruments for the future.

2. Measuring the speed of sound in the air

An experiment which is familiar to most physical students is the speed of sound based on the resonance tube or Kundt's tube [5]. The experiment also allows the student to determine the heat-capacity ratio for various gases in the tube. The process of changing air may be more easily accomplished if the microphone in the tube can be fixed in its position relative to the speaker. The speed of sound, v_s, is related to the frequency f and wavelength λ of a sound wave through the general relation $v_s = fl$, where f and l are usually determined by considering the acoustic resonances of the tube. In particular, for a tube of length L, closed at both ends, the resonance or standing wave condition requires $L = \frac{nl}{2}$, where n is an integer, $n = 1,2,3...$, and therefore the resonance frequencies f_n are given by:

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$$f_n = \frac{v_s n}{2} L \quad \text{or} \quad f_{n+k} = \frac{v_s}{2L} k + f_n \qquad (1)$$

Where k is a number of resonance modes.

Plot a graph of frequency f against the number of resonance modes k, the speed of sound can be calculated by $v_s = 2L \tan a$, with a is the inclination angle of line (1).

3. Implementation

Figure 1 gives a block diagram of this instrument. Sound waves are produced using a speaker that is located at one end of the tube with 0.9m of length. A microphone is used to probe the sound wave in a tube, located in the opposite.

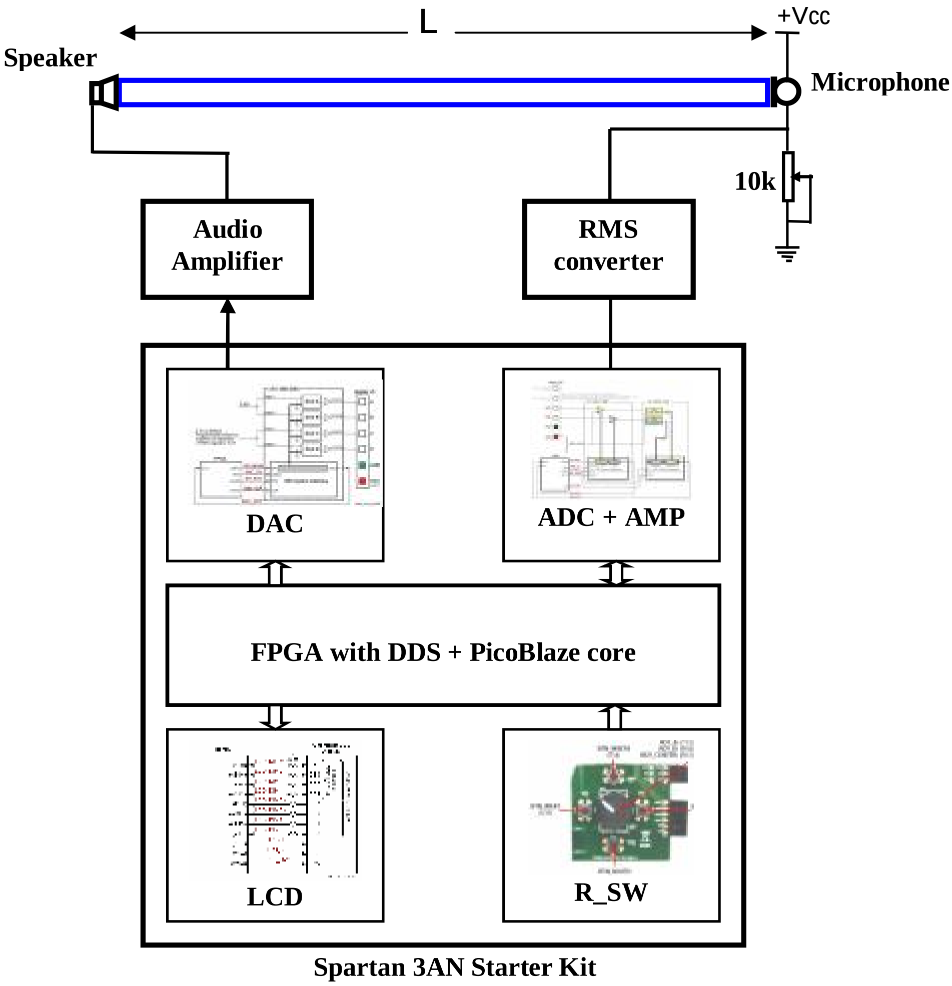

Fig. 1. Functional block diagram of the system.

The Spartan 3AN Starter Kit from Xilinx [6] was used for the hardware, the function generator which control the speaker is implemented in VHDL by using the simple look-up table Direct Digital Synthesis – DDS [7], a on board DAC 12bit LTC2624, and LM386 [8] audio amplifier circuit. The frequency of the generator can be adjusted from 1hz to 100khz and changed every 10Hz per step by using the rotary encoder R_SW. When a speaker vibrates, the sound wave propagates through the tube and is reflected back and forth from each end in the tube. As the wave travels away from the speaker, it will encounter the wave that has been reflected from the end of the tube. If the length of the tube and the wavelength of the sound wave are such that all of the waves are in phase with each other, a standing wave pattern is formed. This is known as a resonance mode for the tube and the frequencies at which resonance occurs are called resonant frequencies. At these frequencies, the sound will appear “louder”, it mean that the amplitude reach to a maximum value. The resistance type of a commercial microphone located in the opposite is used to record the sound inside the tube. Before come to the amplifier and ADC circuit, the signal passed through to a Root Mean Square - RMS converter using AD736 from Analog Devices [9]. The soft 8bits microprocessor using Picoblaze [10] was used to control the operating of ADC, gain of the amplifiers and displays both of the frequency and RMS amplitude of the sound wave. The voltage levels and impedance matching at the inputs and outputs is implemented easily by using some capacitors and potentiometers. DC voltage at the output will indicate the amplitude of sound wave. Therefore, we can determine when the resonance occurs.

4. Results and applications

For the speed of sound measurement purposes mentioned in this work, and due to the form of the signal measured at the output of microphone, the frequency of the signal generator is chosen the range from 1khz to 5khz. The typical 1khz signal at the DAC’s output is shown as figure 2a. Because of using the same a look-up table, the output waveform is identical with full range.

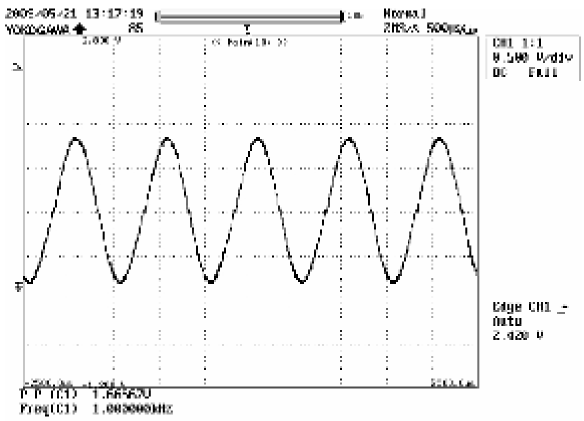

Fig. 2a. signal of DAC’s output.

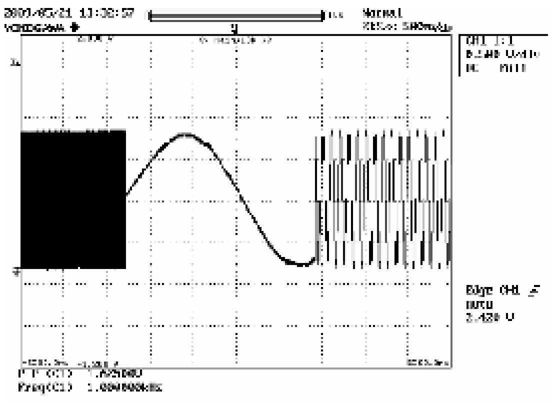

Fig. 2b. the changing of different frequencies.

Figure 2. Signal generated by DDS at the output

Figure 2b show the changing of the signal from 100khz to 0.1hz end then 1khz of frequency, the transient response seems is “immediately”.

The gain of -5 is the current setting loaded into the programmable pre-amplifier is chosen for an input range from 1.4V to 1.9V with centered ground is 1.65V generated via a voltage divider [6]. The maximum voltage at the resonance frequency can be changed from 65mV to 242mV. The graph of the resonance frequency versus the number of resonance modes is shown in the figure 3.

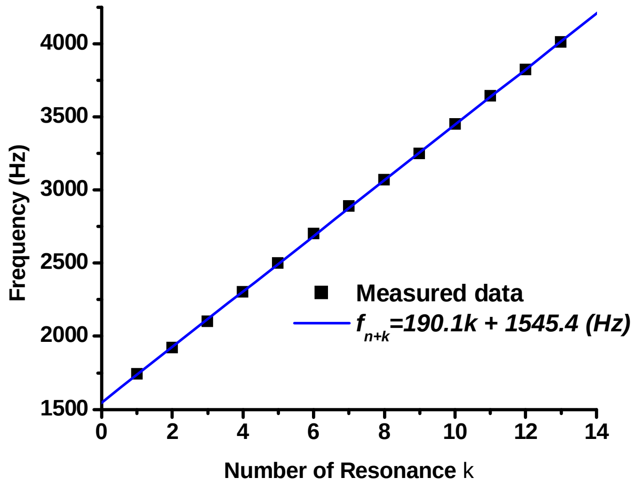

Fig. 3. frequencies *f* against the number of resonance modes *k.*

The speed of sound calculated from formula *v=2Ltana* at room temperature is 20^{o}C is v = 342.18 m/s. This value is the same compared to with that of standard value reported by Scott, at al [11]. By using this value, we can also determine the heat capacity ratio of the air at measured condition γ = 1.384 compared to the standard value is 1.4.

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