Design and Implementation of Audiometric Instrument Based on Microcontroller

Lecturer Ali Abdul Elah Noori
College of Electrical and Electronics Techniques
Foundation of Technical Education, Bagdad, Iraq
aliabdulelahnoori@Gmail.com

Assist. Lecturer Malik Bahnam Abbu Samter
College of Electrical and Electronics Techniques
Foundation of Technical Education, Bagdad, Iraq
maliksamter@yahoo.com

Assist. Lecturer Ghaidaa Abdulrahmaan Khalid
College of Electrical and Electronics Techniques
Commission of Technical Education, Bagdad, Iraq
Ghaidaa٨٥@yahoo.com

Abstract

The aim of this paper is to design and implement an audiometry testing instrument (Audiometer) by using PIC ١٦F٨٧٧A microcontroller that has the capability to apply an audio sound to the patients' ear with a frequency range of (٢٥٠Hz to ٨KHz) with an intensity ranging from (-١٠ to ١١٠ dB), and recording the patients' response through an input device. The instrument hardware was implemented by using a push button switch, headphone circuit, power supplies, two output units using ٢X ١٦ LCD display and RS ٢٣٢ serial port interface connected with Personal Computer (PC) from through the ports COM ١ or COM ٢ and microcontrollers programmer with its special program (Topwin ٦).

The proposed design of audiometer and simulation results of many cases of hearing states are carried out using ISIS ٧ professional simulator and Matlab ٢٠١٠ environment. Finally, Proton IDE Basic compiler (high level language) is used to write a program which is employed to program microcontroller.

Keywords: Audiometry; PIC ١٦F٨٧٧A Microcontroller.

تصمييم وتنفيذ جهاز مقياس السمع بالاعتماد على المسيطر الدقيق

الخلاصة

الهدف من هذا البحث هو تصمييم وتنفيذ جهاز الاختبار السمعي (مقياس السمع) باستخدام المسيطر الدقيق PIC ١٦F٨٧٧A لارسال مدى من الترددات من ٢٠Hz- ٢٠KHz الى المريض ومعرفة استجابته لهذه الترددات من خلال وحدات الاخراج. ينجز التصميم المادي للجهاز باستخدام مسيطر دقيق PIC ١٦F٨٧٧A واحد, مفاتيح ضغط, دائرة السماعة, مجهزات القدرة وحدتين اخراج ؛ عارضة 2 × 16 LCD ومنفذ التوالي RS ٢٣٢ المربوط مع الحاسب الشخصي (PC) من خلال المنافذ COM ١ او COM ٢ ومبرمجة المسيطرات الدقيقة مع برنامجها الخاص (Topwin ٦).

ينفذ التصميم المقترح لجهاز مقياس السمع ونتائج المحاكاة لعدة حالات من حالات السمع باستخدام المحاكي ISIS ٧ Professional وبيئة برنامج Matlab ٢٠١٠. يستعمل برنامج Proton IDE Basic (لغة المستوى العالي) لكتابة البرنامج الذي يستخدم لبرمجة المسيطر الدقيق.

١. Introduction

An audiometer is used to measure the ability of a patient to hear at specific frequencies. Fundamental to this measurement is pure tone measurement. The audiometer is used to generate pure tone signals at specific frequencies within the ٢٥٠ Hz to ٨ kHz range. For each frequency the level of loudness is incremented from soft to loud. The patient is asked at which point he/she starts to hear the sound, which will then represent the patient's hearing threshold at that frequency. The final result is plotted as an audiogram that will be interpreted by medical professionals to determine proper treatments [١].

The weakest sound heard at a selected frequency is the hearing level in decibels (dB HL) for that particular frequency. This is a relative value; the intensity reference is ٠ dB HL, or audiometric ٠, which corresponds to the average threshold response (for a normal intensity range of -١٠ to +٢٥ dB HL) of a group of ١٨- to ٢٥-year-olds with no otologic pathology. The sensitivity of the normal ear varies with frequency; therefore, ٠ dB HL represents different levels of sound pressure at different frequencies. (Minus dB HL readings indicate that hearing sensitivity is greater for that particular frequency than for the average value) [٢].

At present, there are various types of audiometer readily available on the market. They can be different depending on the specifications and features, but generally a dedicated hardware is needed for high-quality and reliable measurements, resulting in high price. In terms of research, historically the earlier work focused on hardware implementation, usually at the integrated circuit (IC) or embedded system levels [٣, ٤]. Techniques such as direct digital synthesis (DDS) have been considered [٥]. As the availability of good-quality personal computer expanded, the focus has shifted towards PC-based systems [٦]. Some has also attempted on integrating other hearing loss measurement features into the same device [٧, ٨, ٩]. Finally, remote hearing scanning and active noise control based on PC have introduced in [١, ١٠] respectively.

The PIC١٦F٨٧٧A microcontroller is manufactured by Microchip [١١]. Currently they are one of the most popular microcontrollers, used in many audio applications [١٢-١٤]. This PIC has chosen to manufacture audiometric test for reasons of generating high precision and flexible pure-tone signal, digitally programmable, (frequency and amplitude of a waveform can be easily adjusted without the need to change the hardware components), in addition to; speed, digital ports ability, memory storage, and number of I/O (input or output) ports. This proposed system contains on push bottom switches, headphone circuit, display output units ٢× 16 LCD design and serial communication design based on PIC١٦F٨٧٧A microcontroller.

This paper is organized as follows: The hardware design for audiometric test is first introduced in Section ٢, the software and simulink design is then described in Section ٣, Testing and results are discussed in Section ٤, and finally, concluding remarks and observations are given in Section ٥.

٢. Hardware Design

The block diagram of the proposed hardware which consists of five basic parts is shown in Fig. (١).

١. PIC١٦F٨٧٧A Microcontroller.
٢. Switches selection circuit.
٣. Headphone circuit.
٤. Output units.
٥. Power supplies.

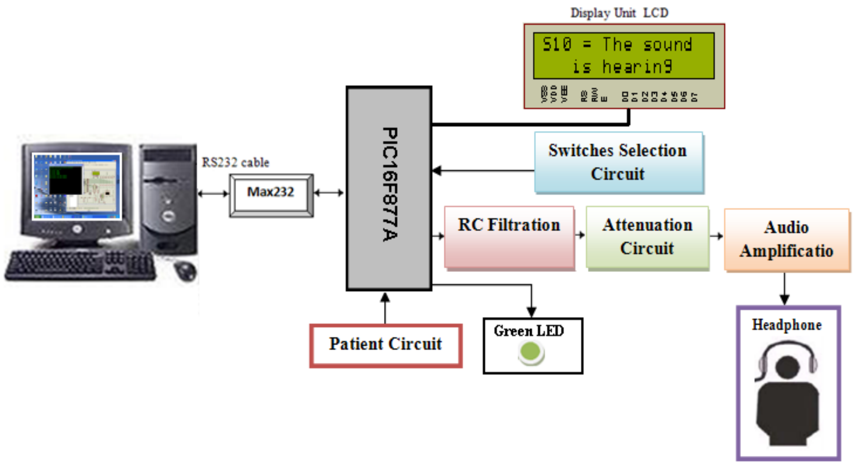


Fig. (١) Block diagram audiometric test based on PIC١٦F٨٧٧A microcontroller.

٢,١. PIC١٦F٨٧٧A Microcontroller

Suitable for various digital applications, the PIC١٦F٨٧٧A RISC microcontroller has five I/O port (٣٣ lines), $8K \times 14$ flash program memory, 256×8 EEPROM data memory, three timer an ٨ bit timer/counter and ١٠-bit ADC, at a clock rate of ٢٠MHz, which is obtained by connecting a crystal oscillator between OSC١ and OSC٢ pins with two ٢٢pF capacitors. The built in power on reset circuitry provides a safe start-up, therefore the Master Clear pin (MCLR) is connected to reset circuit. The pin diagram of PIC١٦F٨٤ is shown in Fig. (١) [١٥].

٢,٢. Switches Selection and Patient Circuit

The push bottom switches S١ to S٨ are connected to microcontroller port B (RB٠-RB٧) to select the range of frequencies from ٢٠Hz-٢٠KHz. S٩ is connected to $\overline{MSLR}$ pin to reset the microcontroller and S١٠ is connected to the pin RD٦ to know patient's response, which is displayed in LCD or PC as message "*The sound is Heard*" in addition to light green LED connected to the pin RD٧. The connections of push bottom switches are illustrated in Table (١).

Table (١) connections of push bottom switches with the PIC١٦F٨٧٧A microcontroller pins.

Switches	PIC pin	Pin No.	Function
S١	RB٠ (input pin)	٣٣	Select ٢٥٠Hz
S٢	RB١ (input pin)	٣٤	Select ٥٠٠Hz
S٣	RB٢ (input pin)	٣٥	Select ١٠٠٠Hz
S٤	RB٣ (input pin)	٣٦	Select ٢٠٠٠Hz
S٥	RB٤ (input pin)	٣٧	Select ٣٠٠٠Hz
S٦	RB٥ (input pin)	٣٨	Select ٤٠٠٠Hz
S٧	RB٦ (input pin)	٣٩	Select ٦٠٠٠Hz
S٨	RB٧ (input pin)	٤٠	Select ٨٠٠٠Hz
S٩	$\overline{MSLR}$ pin	١	Reset circuit
S١٠	RD٦ (input pin)	٢٥	Patient's response
Green LED	RD٧ (output pin)	٢٦	Patient's response

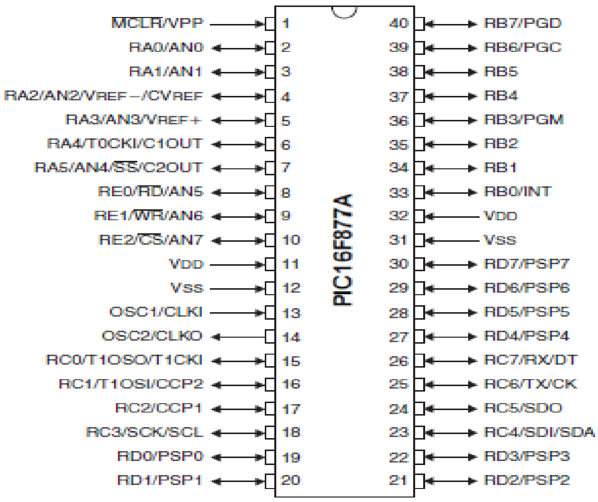


Fig. (٢) Pin connection of PIC١٦F٨٧٧A.

٢,٣. Headphone Circuit

The headphone circuit consists of three main parts; RC filtration, attenuation circuit and audio amplification. The PIC١٦F٨٧٧A microcontroller generates a signal with one or two different frequencies on the specified PIN by using "Freqout" instruction. The generated signal is a square wave and filtering may be required to obtain a smooth signal and to remove the quantization noise are the attenuation module and amplification module. The attenuation circuit is implemented using a ٦-stage (- ٨٠, -٤٠, -٢٠, -١٠, -٥, -٢,٥ dB) logarithm resistive ladder network to achieve the ١٢٠ dB (-١٠ dB to ١١٠ dB) dynamic range with a step resolution of ٥ dB [٨].

Since, the amplitude of the output signal may not be adequate, the audio amplification module is required to provide sufficient current drive and to match the load resistance of the audiometric headphone at ٣٧ Ω [٨].

٢,٤. Output Unit

Two output units were used in this paper, 2 × 16 LCD and RS٢٣٢ serial port. The LCD is alphanumeric display, which is frequently used in microcontroller-based applications. Some of the advantages of LCDs are their low cost and low power consumption. (SC١٦٢C) is one of the most popular LCD modules used in the industry and also by hobbyists. The circuit diagram of the LCD and the PIC١٦F٨٧٧A microcontroller is shown in Fig. (٣) [١٦]

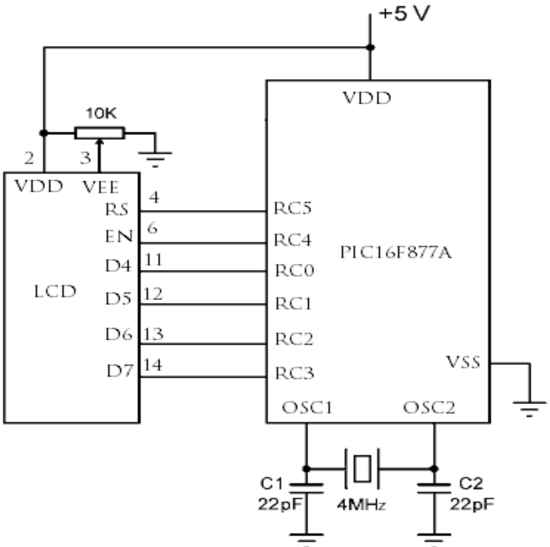


Fig. (٣) circuit diagram between the LCD and the PIC١٦F٨٧٧A microcontroller.

In addition LCD output unit, the RS٢٣٢ serial port can be connected in this instrument. The pins RC٦ and RC٧ of the PIC١٦F٨٧٧A are configured as RS٢٣٢ serial output and input, respectively. RS٢٣٢ voltage levels are ∓١٢V. Normally RS٢٣٢ voltage levels are converted to CMOS levels using RS٢٣٢-level converter chips, such as the MAX٢٣٢ .An RS٢٣٢-level converter chip converts the ٠ to +٥ V output from the microcontroller into ∓١٢V RS٢٣٢ levels. Similarly, the RS٢٣٢-level output from a device is converted into ٠ to +٥ V suitable for the microcontroller inputs. MAX٢٣٢ is a ١٦-pin IC having dual RS٢٣٢ transmitters and receivers. This IC requires external capacitors for its operation to adjust the voltage level differences between the PC-based logic and the PIC-based logic as shown in Fig. (٤) [١٧].

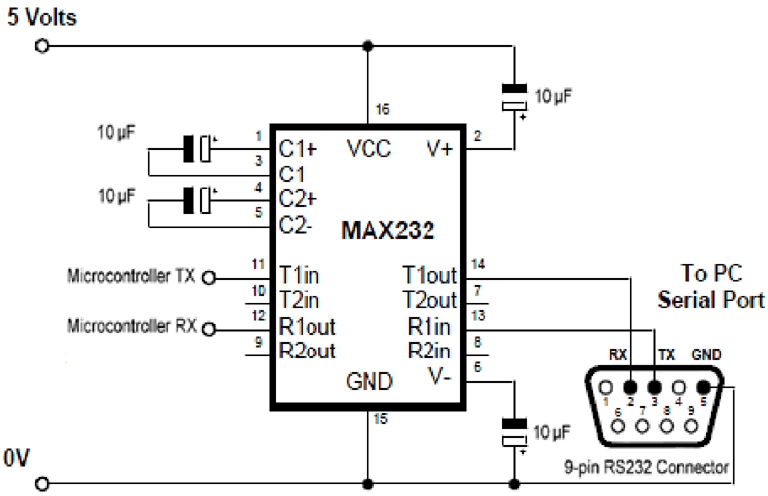


Fig. (٤) MAX٢٣٢ RS٢٣٢-level converter.

٣. Software and Simulation

The software is written using Proton Basic IDE; the Proton language is a high level language consisting of ١٦٥ instructions. The proposed coding by using Proton IDE compiler and Software flowchart of the audiometric test are respectively shown in Fig. (٥) and (٦).

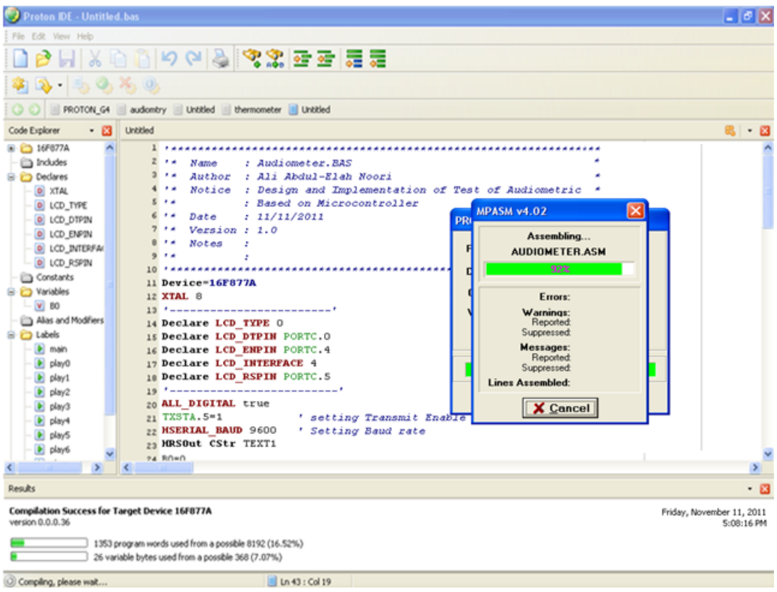


Fig. (٥) Proton IDE coding of audiometric test.

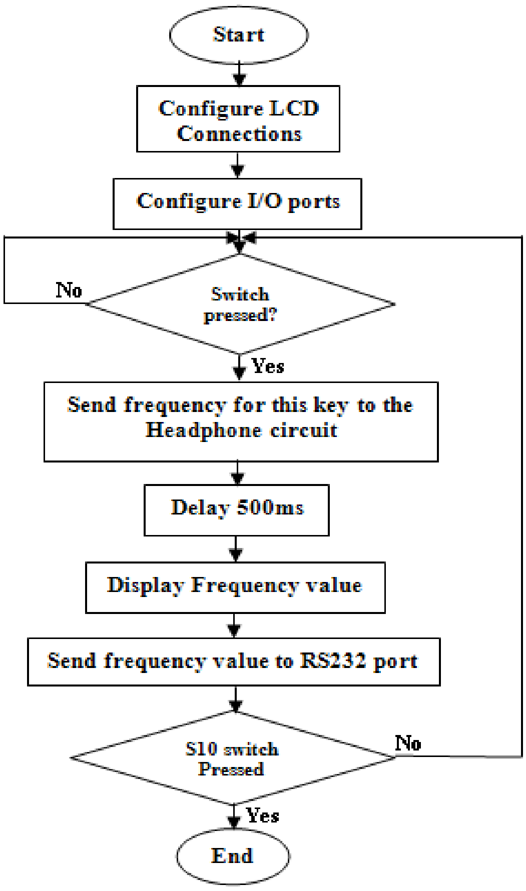


Fig. (٦) The proposed flowchart of PIC microcontroller program.

The hex file of Proton IDE is downloaded into microcontroller programmer (Top programmer) through Topwin٦ Program which is accompanied with the microcontroller programmer. The Top PIC programmer device designed to operate with the USB port is shown in Fig. (٧). After the PIC microcontroller programming is finished, the PIC١٦f٨٧٧A becomes ready to connect in hardware circuit.

Fig. (٧) Top programmer and Topwin٦ program disk.

The hardware design is implemented by "ISIS ٧ professional simulator" to simulate the electronic circuit of the audiometric test instrument as shown in Fig. (٨).

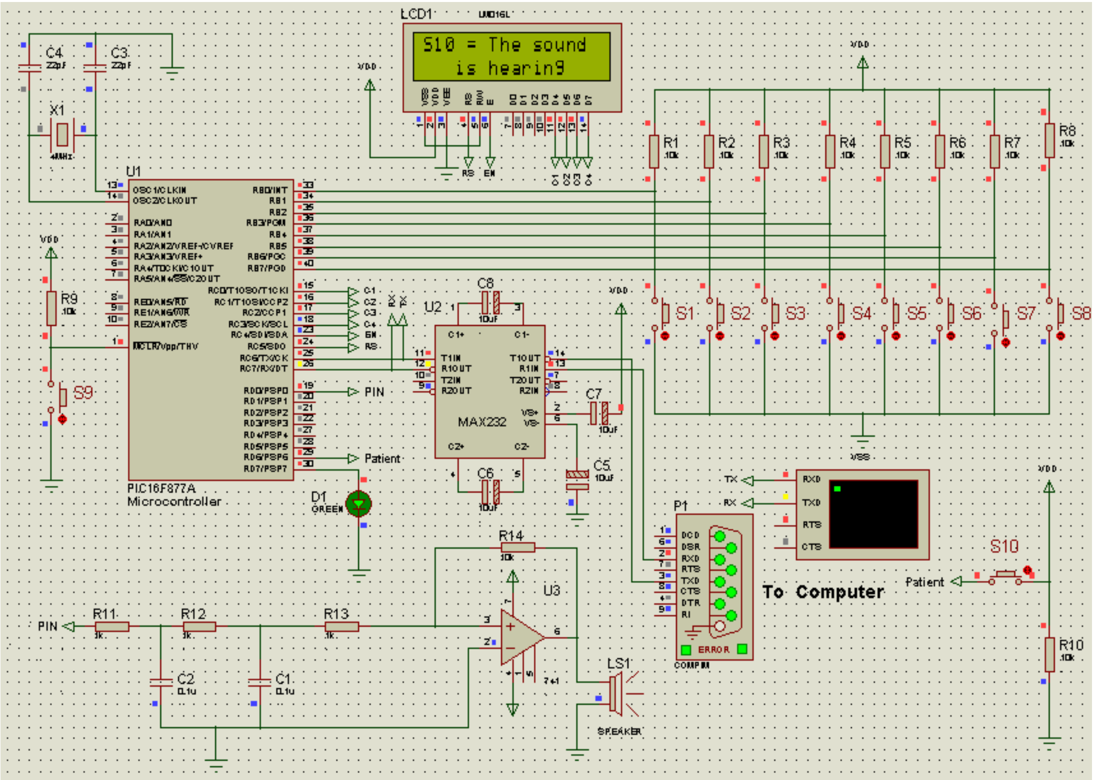


Fig. (٨) Electronic circuit of test of audiometric instrument.

٤. Testing and Results

In the experimental work, source code is written in the Basic language. The source file is then compiled by invoking the Proton IDE program. The code was tested using ISIS ٧ Professional simulator. When the examiner presses one of the S١ – S٨ switches, the instrument applies a sound wave of the corresponding frequency to the patients' ear through the headphone. Simultaneously, the frequency value is displayed on the LCD. The patient presses S١٠ when he hear the sound, causing a green LED to be lite and displaying a message of "the sound is heard" on the LCD screen. The values of frequencies are displayed on an LCD screen as shown in Fig. (٩).

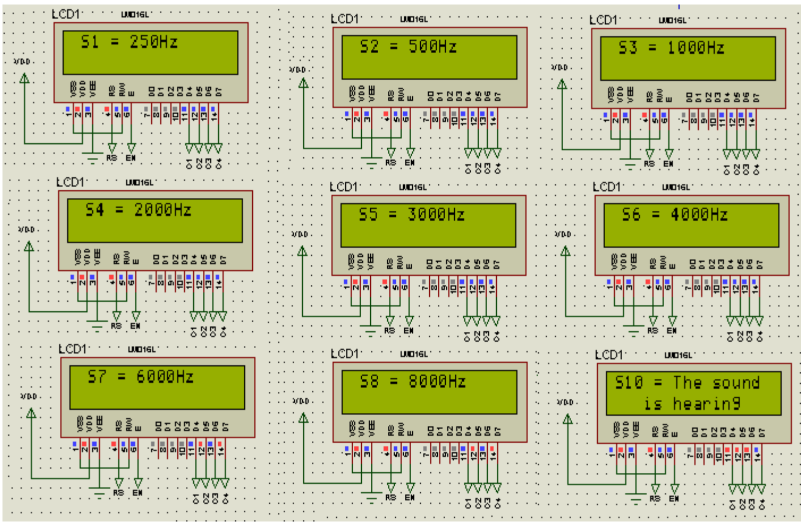


Fig. (٩) Frequencies values display in LCD after pressing on different switches.

In addition LCD output unit, the RS٢٣٢ serial port can be connected with COM١ or COM٢ in PC to display values of frequencies through “Smarterm terminal emulation program”. This program can be activated on the PC to communicate with the audiometric instrument. The frequency range obtained is shown in Fig. (١٠) when the SmartTerm terminal emulation program is used.

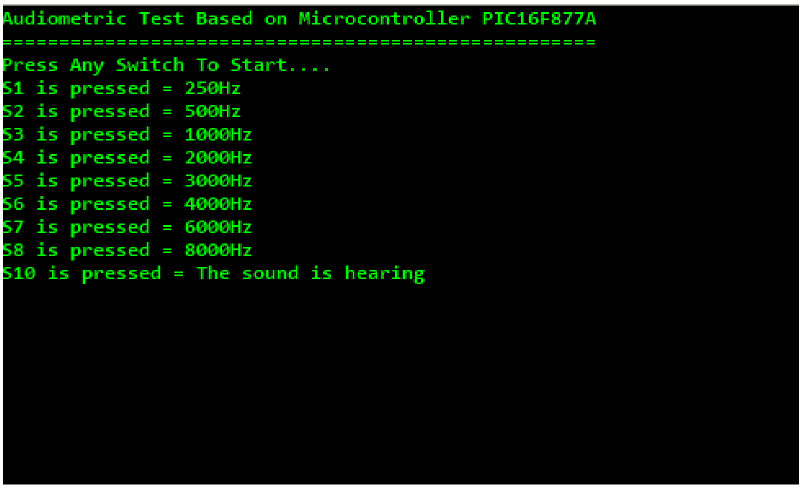
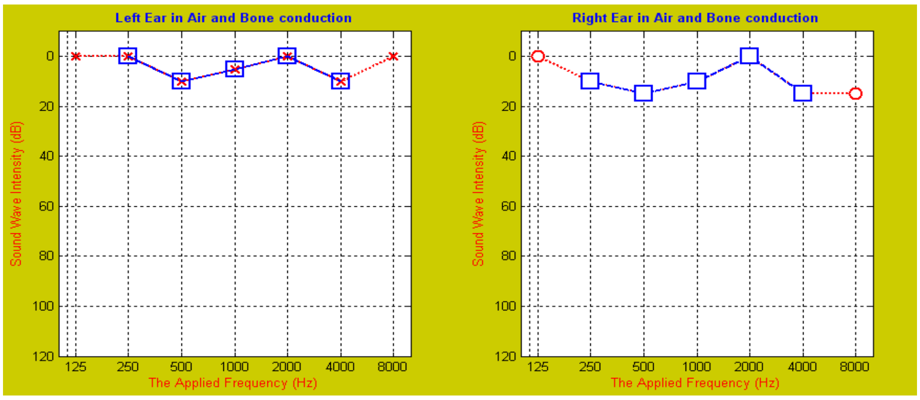
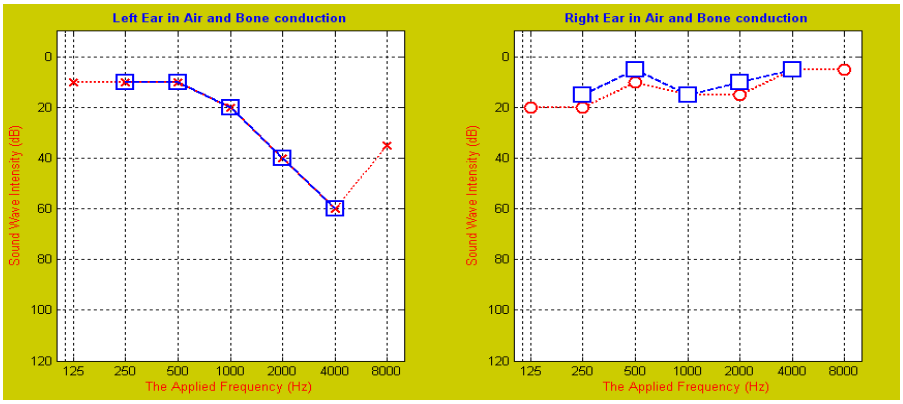


Fig. (١٠) Frequencies values display in PC after pressing on different switches

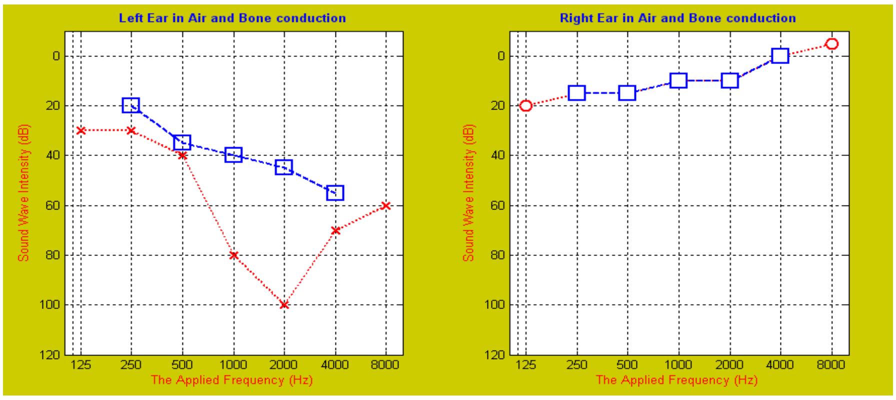
The simulation results of audiometer cases by using the proposed hardware are implemented in environment of Matlab ٢٠١٠ program to examine the left and right ear in different case of hearing as shown in Fig. (١١)



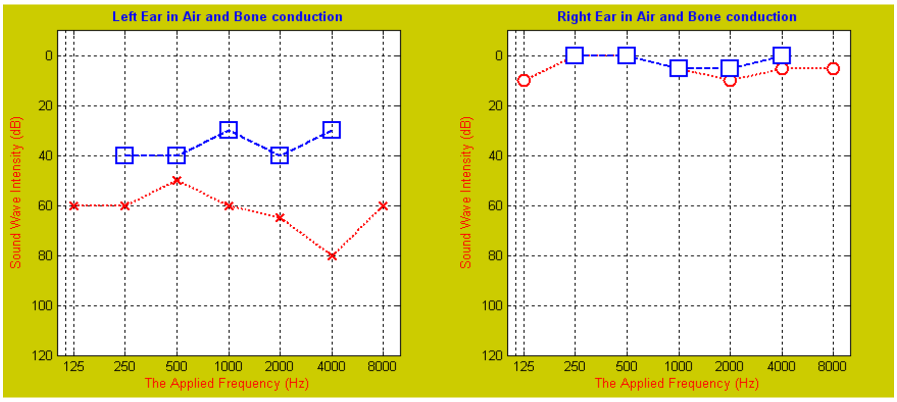
(a)



(b)



(c)



(d)

Fig. (١١) Haering cases: (a) Normal case, (b) Sensonural hearing loss case, (c) Conductive hearing loss case, (d) Mixed hearing loss case.

٥. Conclusions

Many conclusions can be derived in this paper; the most important results can be summarized as follows:

a. The audiometric instrument based on PIC microcontroller has been designed and implemented successfully. The simulation and hardware implementation results have been presented to verify the feasibility of the system.
b. Using PIC microcontroller unit, the frequency range and amplitude can be easily changed through programming without further hardware changes or by increasing push bottom switches connected to PIC microcontroller.
c. The audiometric testing instrument based on PIC microcontroller offers high performance at low cost, and hence is suitable for commercial and industrial applications.
d. The audiometric testing instrument based on PIC microcontroller is portable and easy to use.

References

[١] A. Hemakom, A. Noymai, P. Israsena, S. Boonyanukul & C. Chinnarat," Remote Hearing Screening As Part of Auditory Telerehabilitation; A Preliminary Report" *International Conference on Virtual Rehabilitation*, ٢٧ – ٢٩ June, ٢٠١١.

[٢] Bulletin, *Audiometric Testing: Information for Employers and Workers*, Alberta, January ٢٠٠٨. http://industry.alberta.ca/whs-ohs

[٣] M. Maloberti, S. Brigati, F. Francesconi, G. Grassi, D. Lissoni, P. Malcovati, A. Nobile, & Poletti, "An ٠,٨ μm CMOS Mixed Analog Digital Integrated Audiometric System" Proc. *IEEE Solid-State Circuits Conference*, , ١٩٩٨, pp. ١١٦ – ١١٧.

[٤] P. Malcovati, "Design of Integrated Circuits for Audiometric Applications", *Proc. IEEE International Symposium on Circuits and Systems*, , ٢٠٠١, pp. ١٧١ – ١٧٤.

[٥] H.C. Wu, L.P. Yang, C.H. Chen, S.T. Young, & T.S. Kuo, "A Low-cost Architecture of Audiometer Based on Direct Digital Synthesizer", *Proceedings of The first Joint BMES/EMBS Conferences Serving Humanity, Advancing Technology*. Vol. ٢, October, ١٩٩٩, pp. ٨٩٤, ١٣-١٦.

[٦] C.A. Martinez-Baez, L.F. Borjon, & A. Noyola, "Manual And Automatic Programmable Audiometer", *Proc. IEEE Inter Conf on Engineering in Medicine and Biology Society*, Vol. ١٣, ١٩٩١ , pp. ١٩١٥ – ١٩١٦.

[٧] K. Kochanek, L. Sliwa, J. Zajac, & H. Skarzynski, "A Universal Computer Audiometer for Objective Hearing Testing and Screening," *Proc. Medical Measurement and Applications*, pp. ١ – ٣, ٢٠٠٧.

[٨] S. L. Tan, S. K. Loh, & W. C. Chee, "Speech-Enabled Pure Tone Audiometer", *Proc. IEEE Intelligent Signal Processing and Communication Systems*, pp. ٣٦١ – ٣٦٤, ٢٠٠٧.

[٩] Y. Faycal, B. Wahiba, B. Lotfi, B. Ratiba, & A. Benia, "Computer Audiometer for Hearing Testing", *Proc. Advances in Electronics and Micro-electronics*, ٢٠٠٨, pp. ١١١ – ١١٤.

[١٠] D. Azeez, M. A. Ali, H, Husain, G. K. Beng, C. Umat & R. Mustafa, “Implementation of Active Noise Control for Hearing Test Application Using PC” *International Conferernce on Instrumentation, Communication, Information Technology and Biomedical Enginerring*, pp. ١-٤, ٢٠٠٩.

[١١] Website of Microchip Technology, Inc. http://www.microchip.com/١٠١٠/index.htm,

[١٢] A. Lay-Ekuakille, G. Vendramin١, & A. Trotta, “Design of an Energy Harvesting Conditioning Unit for Hearing Aids” *٣٠th Annual International IEEE EMBS Conference*, pp. ٢٣١٠-١٢١٣, ٢٠-٢٤ August, ٢٠٠٨

[١٣] K. R. Kumer, & R. Seetha, “Development of Reciver Stimulator For auditory Prosthesis” *Internation Journal of Computer Science Issues*, Vol. ٧, No. ٣, ٢٠١٠, pp. ٢٣-٢٩.

[١٤] Cheng-Yuan Chang & Sheng-Ting Li, “Active Noise Control in Headsets by Using a Low-Cost Microcontroller” *IEEE Transations on Industrial Electronics*, Vol. ٥٨, No. ٥, , May ٢٠١١, pp. ١٩٣٦-١٩٤٢.

[١٥] A. V. Deshmukh, *Microcontrollers Theory And applications*, Tata McGraw-Hill, ٢٠٠٥.

[١٦] I, Dogan, *PIC BASIC Projects Using PIC BASIC and PIC BASIC PRO*, ELSEVIER, ٢٠٠٦.

[١٧] S. Lee, Y. Li, & V. Kapila, “Development of a Matlab-Based Graphical User Interface Environment for PIC Microcontroller Projects” *American Society for Engineering Education Annual Conference & Exposition*, S. ٢٢٢٠, ٢٠٠٤.