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Screening Audiometer

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Abstract

The screening audiometer gives sinusoidal acoustic output with easily selectable frequency and level (calibrated in dBHL), for preliminary testing of hearing thresholds. It provides test tones of 250 Hz, 500Hz, 1 kHz, 2 kHz and 4 kHz. Intensity of the output sound can be varied in discrete steps, namely, 0 dBHL, 20 dBHL, 40 dBHL, 60 dBHL for speaker and 20 dBHL, 40 dBHL, 60 dBHL, 80 dBHL for the headphone, for the selected frequency. It is equipped with the facility to switch between speaker and headphone calibration tables. It can also store audiometric data of a user and transfer it to computer using serial port at the user's request. It accomplishes all these operations using 5 switches. It has been designed using a microcontroller, keys, LCD for user input and control, digital to analog converter, a tone generator chip for sinusoidal waveform generation , a digitally controlled volume control chip for level control, NV RAM chip as memory and a chip for serial data transmission.

1. Introduction

Audiometry is the technique to identify and quantitatively determine the degree of hearing loss of a person by measuring his/her hearing sensitivity. In audiological investigations, the hearing sensitivity is tested for pure tones, speech or other sound stimulus. The electronic instrument used for measuring hearing threshold level is called an audiometer. A screening audiometer is a low cost portable instrument for preliminary testing of hearing thresholds. Normally it should provide frequencies of 125 Hz, 250 Hz, 500 Hz, 750 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3kHz, 4 kHz, 6kHz and 8 kHz and intensity levels of -10 dBHL to 110 dBHL with steps of 10 dB [6]. Furthermore, it should have provision for storing user's data on the device and also to send and retrieve data from a PC. It also should provide the flexibility for the user to switch between speaker and headphone. It is important that the electrical output level should be selected to compensate for frequency dependent relation between sound pressure level (SPL) and hearing level (HL) and the acoustic response of speaker/headphone.

In acoustic measurements, sound level is often given in dB, taking sound pressure of 20 µPa as the reference level, and is known as sound pressure level (SPL).

$$\text{Sound level in dB SPL} = 20 \log (\text{measured sound level} / 20\ \mu\text{Pa})$$

However, in audiometry the sound level of pure tones is given in dB by taking average hearing threshold of normal hearing young adults as the reference, and is known as hearing level (HL) [2].

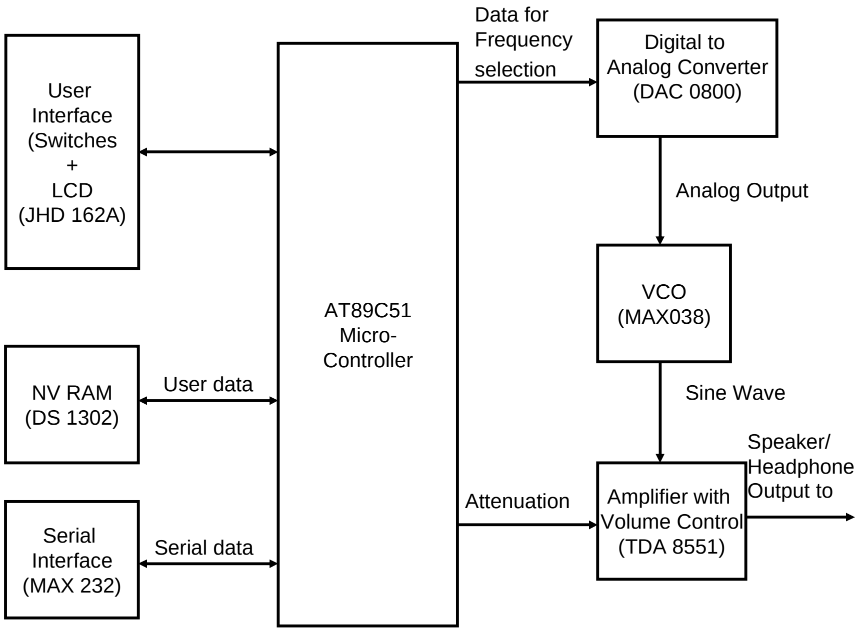

Fig 1: Block Diagram of the audiometer

2. Design details

The block diagram of the circuit used is shown in Fig 1.

2.1 User interface

For the user interface, five switches and a LCD display have been provided. There are two modes of operation – User Mode and the Configuration Mode. Audiometery should be performed in the User mode. Configuration mode is used to select between speaker and headphone as the sound output device. The audiometery test data for a user can be transferred to a PC via RS232 port. This operation also requires the device to be in Configuration mode. While in the user mode, frequency of operation can be increased or decreased by the respective switches provided. Out of 0 dBHL, 20 dBHL, 40 dBHL, 60 dBHL, 80 dBHL output levels can be selected by varying the signal attenuation using the two switches for increasing and decreasing levels respectively. They have been connected to port 1 of the microcontroller. Sound can be presented/stopped with the help of ‘present sound’ switch. To save a particular frequency and attenuation level ‘increase attenuation’ and ‘decrease frequency’ switches must be pressed simultaneously. To get into the configuration mode, ‘decrease attenuation’ and ‘increase frequency’ switches must be pressed simultaneously.

Configuration mode provides two functionalities to the user:-

1. Select the sound output device as speaker or headphone.
2. Transfer the audiometry test data to a PC via RS232 serial port interface.

A menu is displayed on the LCD. ‘Increase frequency’ and ‘Decrease volume’ switch is used to go to the menu option from user mode and vice-versa. ‘Decrease frequency’ and ‘increase volume’ switch is used to save the current users’ data. To select a particular option ‘present sound’ switch must be pressed.

2.2 Microcontroller

The core of the circuit is the microcontroller, IC1 (AT892C51), whose circuit diagram is as shown in Fig. 2. IC1 microcontroller has been used for the digital part of the circuit. This works on 5V input supply with a crystal oscillator of 12 MHz frequency. Port 1 has been used for giving the input to the microcontroller. The five switches on this port control the various operations of the microcontroller. Port 0 has been used for providing the input pulses to the volume controller and to give 6- bit input to digital to analog converter which in turn gives analog input to sine wave generator for selecting the appropriate frequency which gets displayed on LCD. Port 3 is used for data input to LCD (Jhd162A) and three pins from port 2 have been used to provide control signals to LCD. Port 2 is further used to provide signals to serial interface chip and NV RAM.

2.3 Attenuation Level Control

The integrated chip being used for level control is IC3 which is TDA 8551 and its circuit diagram is as shown in Fig. 3. IC3 is a one channel audio power amplifier, capable of delivering a maximum of 1W output power to an 8 Ω load using a 5V supply. The volume level is changed by UP/DOWN pulses. Up pulses decreases attenuation and down pulse is from 2.5V to 0V which is provided by the microcontroller. In maximum volume control setting, attenuation is -20 dB and in the minimum volume control setting the typical attenuation is as low as 60 dB. The attenuation can be set in 64 steps by UP/DOWN pin, each step of 1.25 dB. When the supply voltage is initially connected, the initial state of the volume is an attenuation of 40 dB, with a total gain of -20 dB. This IC reduces the cost of design as a separate amplifier is not needed.

2.4 Sine Wave Generator

The IC which is being used to generate sine waves at different frequencies is IC 4 which is MAX038. The circuit diagram for the same is shown in Fig. 4. IC4 is a high frequency, precision function generator producing accurate, high frequency triangle, saw tooth, sine, square, and pulse waveforms with a minimum of external components. Sine, square or triangle waveforms can be selected at the output by setting the appropriate code at two TTL-compatible select pins. Frequency can be selected from 0.1 Hz to 20 MHz by varying the sink current at pin number 10 of the IC and the value of the capacitor connected between pin 5 and ground. The typical value of total harmonic distortion for sine wave output is 2%. Its frequency temperature coefficient for the case when FADJ (pin 8) is 0 volts is 600 ppm/C .Pin 8 of the IC can be used for the fine control of the frequency. The output signal for all waveforms is a 2V p-p signal that is symmetric around ground .IC 4 operates with ± 5V ±5% power supplies. The charging and discharging currents are controlled by the current flowing into I_{IN}, the current in the I_{IN} can be varied from 2μA to 750μA. The output frequency is inversely proportional to capacitor C_f (represented by C7 in the circuit diagram).

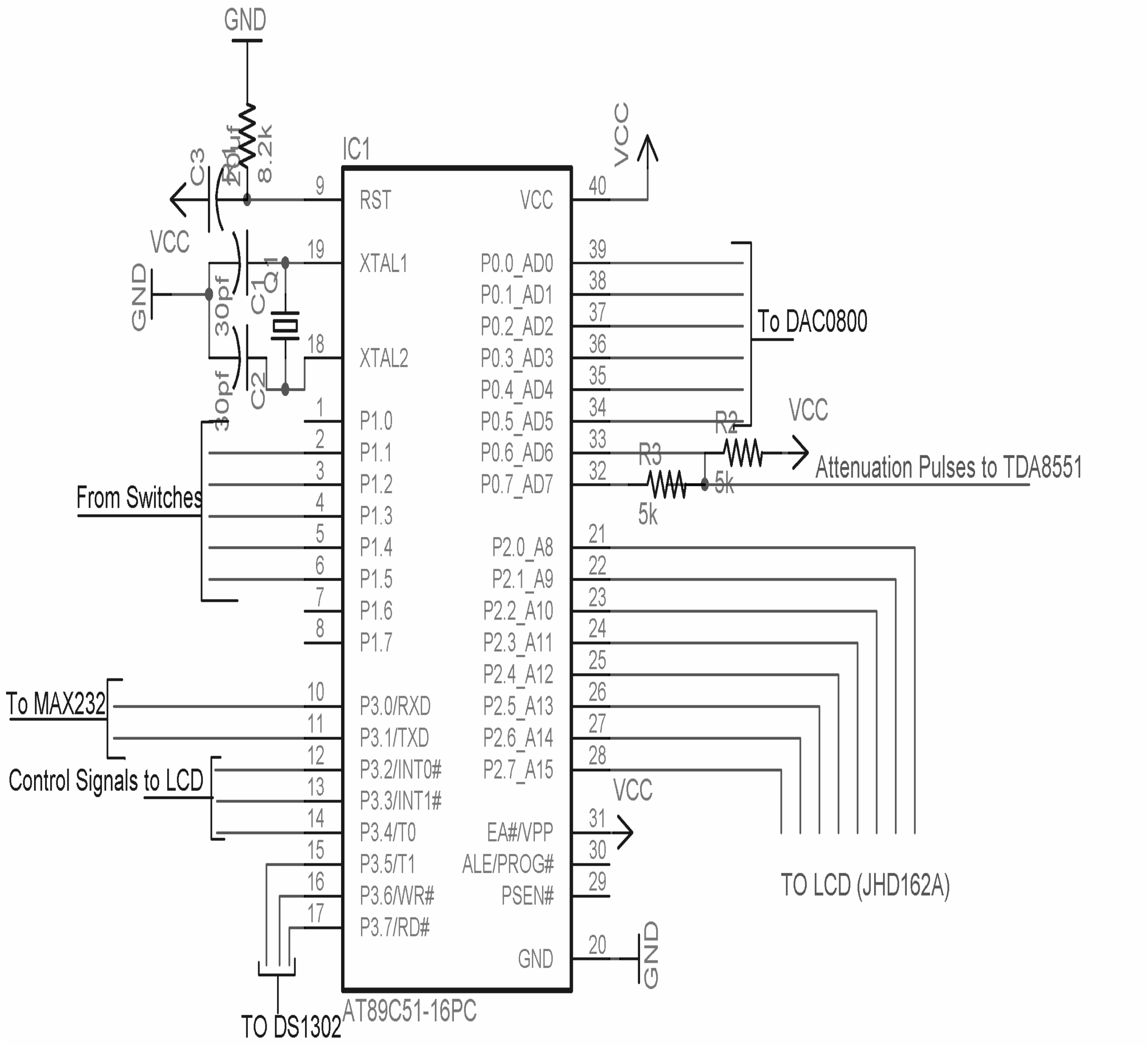

Fig 2: AT89C51 Circuit Diagram

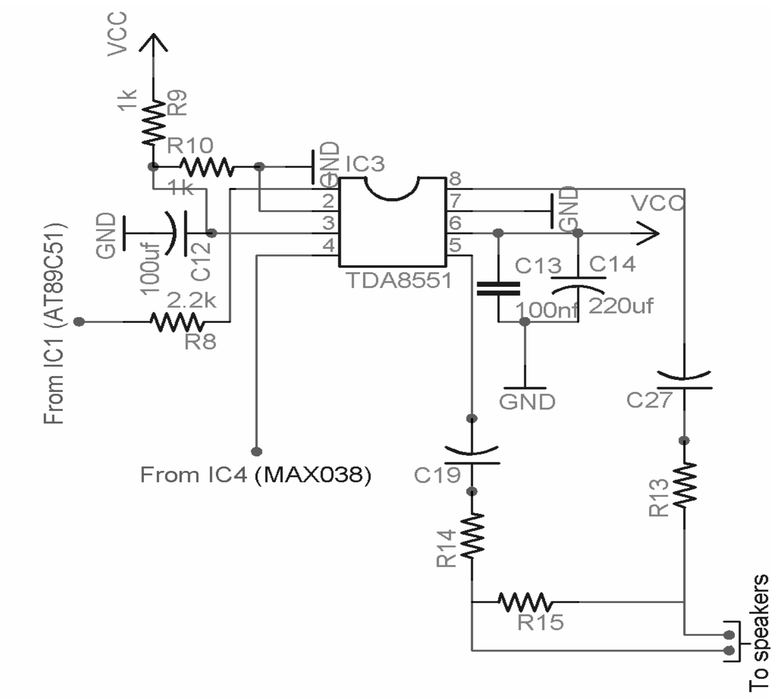

Fig 3: TDA 8551 Circuit Diagram

The module had to be designed to work for frequencies between 250 Hz to 4 kHz. The discrete frequencies to be selected are 250 Hz, 500 Hz, 1 kHz, 2 kHz, and 4 kHz. The output frequency of IC4 can be changed either by changing the ratio I_{IN}/C_{OSC} (where IIN is the sink current at pin 10 and C_f is the capacitor connected between pin 5 and ground) or by changing the voltage at pin 8. Since there has to be only one control for changing the frequency, pin 8 was grounded through a resistor and hence the output frequency will be I_{IN}/C_{OSC}. The input to pin 10 is voltage through a resistor. By changing this voltage and keeping the capacitor value constant we can sweep the required frequency range. The voltage is changed using output of digital to analog converter. Duty cycle of output waveform is kept at 50% by grounding pin 7 of the IC.

Compared to another waveform generator IC's which are readily available like ICL8038 and XR038, IC4, although costlier, has better frequency stability and low distortion.

The output frequency of the chip had to be calibrated using different bit sequences from IC2. The results of the test performed have been shown in Table 1.

2.5 D/A Converter

The chip used as D/A converter is IC2 shown in Fig. 5 which is DAC0800. IC2 is a monolithic 8-bit high-speed current-output digital-to-analog converter featuring typical settling times of 100 ns. It can be operated over ±4.5 ±18 V supply range with power dissipation only 33 mW with ±5 V supplies and is independent of the logic input states. IC2 series also features high compliance complementary current outputs to allow differential output voltages of 20 V p-p with simple resistor loads. It has been operated on

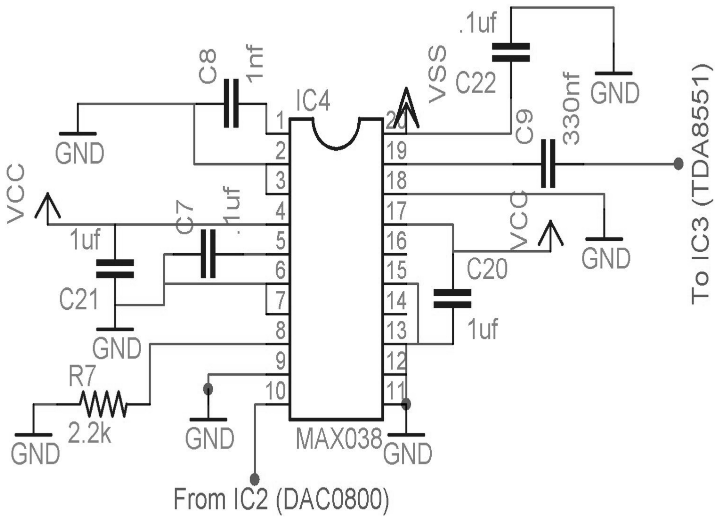

Fig 4: MAX 038 Circuit Diagram

Table 1: Frequency output from MAX 038 along with bits sent to DAC 0800

Serial No.	Frequency (Hz)	Input voltage required for MAX038 from DAC. (in volts)	Input to DAC (6 MSB's)
1	280	.18	000010
2	520	.31	000100
3	1000	.63	001000
4	2000	1.28	010000
5	4000	2.52	100000

±5 V supply with a reference current of 2.27 mA. It has been used to provide analog voltage to IC4 for producing appropriate frequency sine waves. Out of the 8 digital inputs only the upper 6 bits have been used and the 2 LSB's have been permanently grounded.
Other option for providing analog voltages to IC4 is to use a simple resistor divider network. This option although cheaper had much fluctuation of voltages as compared to the output from IC2.

2.6 NV RAM

The chip used as NV RAM in the product is IC6 which is DS1302. It contains 31 bytes of static Ram. It has been used to store a user's audiometric data i.e. minimum attenuation levels at which sound is heard for different test tones presented by the device. It communicates with a microprocessor via a simple serial interface. Apart from using it as a NV RAM it can also be used as a real time clock. The clock can provide minutes, hours, day, date, month, and year information. The clock operates in either the 24-hour or 12-hour format with an AM/PM indicator.

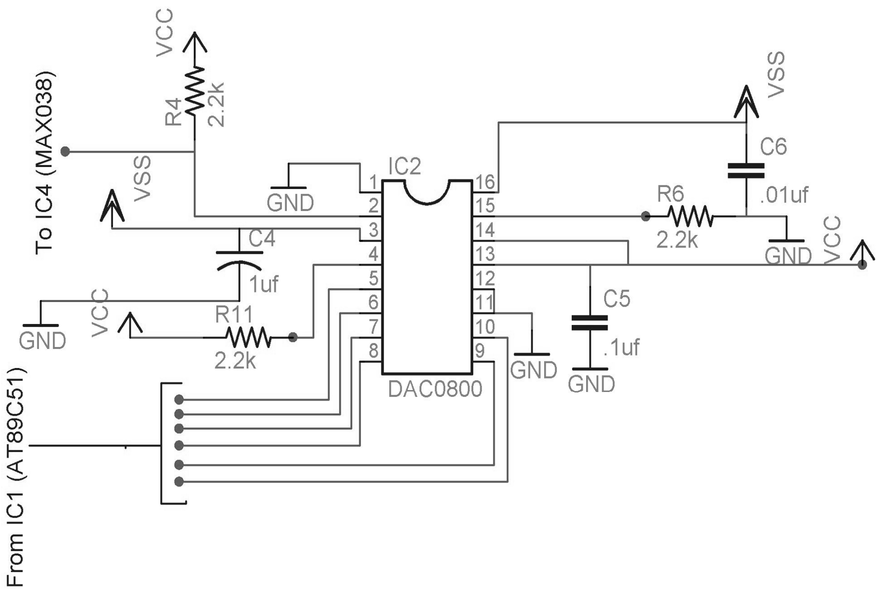

Fig 5: DAC 0800 Circuit Diagram

Interfacing the DS1302 with a microprocessor is simplified by using synchronous serial communication. Only three wires are required to communicate with the clock/RAM: CE, I/O (data line), and SCLK (serial clock). Data can be transferred to and from the clock/RAM 1 byte at a time or in a burst of up to 31 bytes. IC6 is designed to operate on very low power and retain data and clock information on less than 1μW.

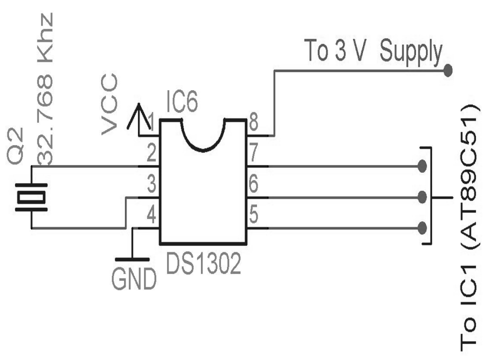

Fig 6: DS 1302 Circuit Diagram

2.7 Serial Interface

IC5 which is MAX232 has been used for serial interface. The terminal unit has to transmit and receive data from the computer. As a result, UART of the microcontroller is being used for the serial communication of data. The TXD (transmit data) and RXD (receive data) pins of IC1 are used for this purpose. These pins are compatible with TTL logic levels. RS-232 logic levels use +3 to +25 volts to signify a "Space" (Logic 0) and -3 to -25 volts for a "Mark" (logic 1). IC5 has to be used to convert the TTL logic levels to RS232 logic levels. This IC requires a 5V power source which is same as that of microcontroller. An external charge pump is required which is implemented using 1µf capacitors (C23, C24, C25, C26). The transmission lines of IC5 are connected to a DB-9 male pin.

2.8 Power Supply

Positive and negative 5 V supply is needed to run the circuit. The supply from the mains is fed to a 12-0-12 transformer. Full wave rectification of this done using a full wave bridge rectifier, which produces both positive and negative cycles. Positive cycles are fed to 7805 from where we obtain 5 V supply and negative cycle is fed to 7905 which gives -5 V output. The circuit diagram is as shown in Fig 8.

2.9 Display

The display used is two line 16 characters LCD (JHD162A). It provides the visual interface needed for displaying menu (non-testing mode) and current frequency of operation along with the current attenuation level (testing mode). Port 2 and Port 3 pins of the microcontroller are used for input to LCD.

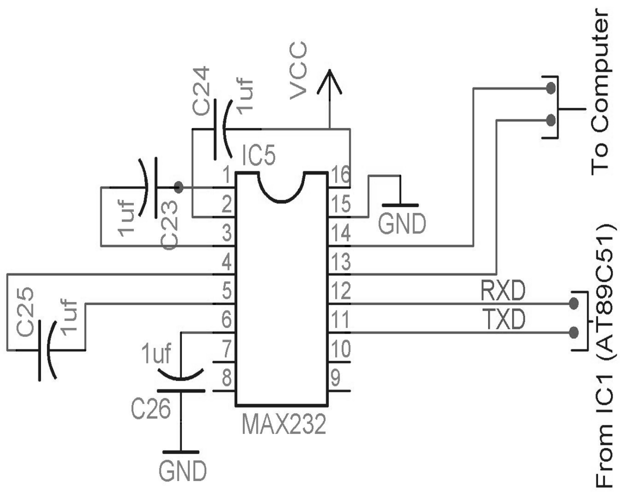

Fig 7: MAX 232 Circuit Diagram

3. Assembly and testing

The circuit has been assembled on a PCB and all the functions have been tested. Sound level meter was used to find the sound level at a distance of 30 cms from the speaker. The results have been summarized in Table 3A. Tests were conducted for a particular user to find the voltages corresponding to comfortable hearing and threshold hearing, with both speaker and headphone. The results for these have been summarized in the Appendix in Table 4A and 4B. The attenuation shown has been measured from the initialization point.

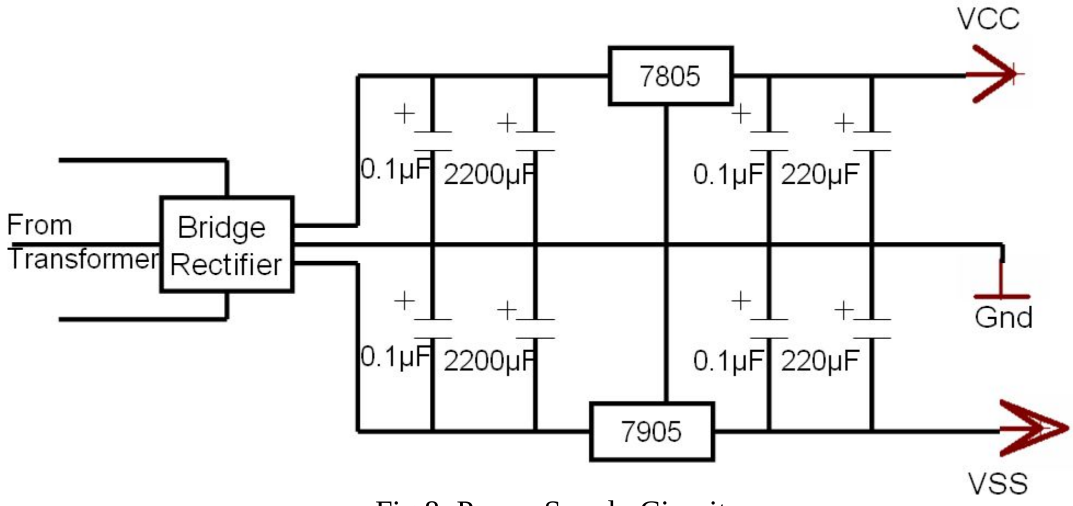

Fig 8: Power Supply Circuit

3.1 Supply requirements

The current readings have been measured with and without connecting the speaker. The maximum current drawn by circuit block has been summarized in Table 2A and Table 2B.

Table 2A: Current drawn by various circuit blocks (without connecting the speaker)

	MAX 038	TDA 8551	AT89C51	DAC 0800	TOTAL
I+ (in mA)	24	10	6	4	44
I- (in mA)	31	-	-	9	40

Table 2B: Current drawn by various circuit blocks (after connecting the speaker)

	MAX 038	TDA 8551	AT89C51	DAC 0800	TOTAL
I+ (in mA)	33	28	11	7	79
I- (in mA)	50	-	-	11	61

Table 3A: Readings from sound level meter at a distance of 30 cms.

Frequency	Vpp (in Volts)	Sound Level (dBSPL)
280 Hz	7.4	77
520 Hz	7.4	82.6
1 kHz	7.4	97
2 kHz	8	99.4
4 kHz	8	84.2

4. Summary

Screening audiometer designed can be used for preliminary testing hearing of people. It can be used for early detection of hearing losses. This is an easy to use, portable digitally operated device. There are five frequencies and five attenuation levels which can be selected by the user. It can be operated with 230 Volts ac mains.

Future scope

The design which has been implemented into a product still has scope for improvement. The design can be improved in the following ways listed below.

1. Digital synthesizer IC's are an alternative option for tone generation of variable frequency. They work on a single supply of 5V as compared to ±5 V supply of MAX038. And also the current requirement of DDS is around 30 mA which is much less than the total current requirement of MAX038. Comparing with MAX038 its frequency stability is much high.
2. Battery can be used in place of Mains supply to run the circuit.

References

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Appendix

A. Test Results

Table 4A: Test results with speaker with subject at a distance of 30 cms.

Frequency	Testing Criteria	Amplification (in dB)	V (p-p) (in Volts)
250 Hz	Max Vo (p-p)	25	4
	Comfortable Hearing	13.75	1.2
	Threshold of Hearing	-3.75	0.15
500 Hz	Max Vo (p-p)	30	6.8
	Comfortable Hearing	11.25	0.75
	Threshold of Hearing	-12.5	0.05
1 kHz	Max Vo (p-p)	31.25	6.8
	Comfortable Hearing	10	0.6
	Threshold of Hearing	-18.75	0.02
2 kHz	Max Vo (p-p)	31.25	6.8
	Comfortable Hearing	10	0.6
	Threshold of Hearing	-18.75	0.022
4 kHz	Max Vo (p-p)	32.5	7.6
	Comfortable Hearing	10	0.6
	Threshold of Hearing	-1.5	0.025

Table 4B: Test results with headphone with headphone

Frequency	Testing Criteria	Amplification (in dB)	V (p-p) (in Volts)
250 Hz	Max Vo (p-p)	25	4
	Comfortable Hearing	13.75	0.2
	Threshold of Hearing	-3.75	0.004
500 Hz	Max Vo (p-p)	30	6.8
	Comfortable Hearing	11.25	0.14
	Threshold of Hearing	-12.5	0.003
1 kHz	Max Vo (p-p)	31.25	6.8
	Comfortable Hearing	10	0.12
	Threshold of Hearing	-18.75	Can't be measured
2 kHz	Max Vo (p-p)	31.25	6.8
	Comfortable Hearing	10	0.1
	Threshold of Hearing	-18.75	Can't be measured

4 kHz	Max Vo (p-p)	32.5	7.6
	Comfortable Hearing	10	0.084
	Threshold of Hearing	-1.5	Can't be measured

B. User Manual

Power

Connect the 3-pin plug into a 230V AC mains source.
LCD will display 250 Hz as the frequency and 20 dBHL as the attenuation level.
Various key functionalities and corresponding uses have been listed below.

Functions

There are two modes of operation:
A) User Mode
B) Configuration Mode

<u>User Mode</u>
Switch 1 - Increase frequency
Switch 2 - Decrease frequency
Switch 3 - Increase volume
Switch 4 - Decrease volume
Switch1 + Switch4 – Changes the mode to configuration mode.
Switch2 + Switch3 – Current hearing level is saved.
Switch 5 – To toggle between present sound and mute condition

<u>Configuration Mode</u>
Switch 1 - Go to the previous menu option
Switch 2 - Go to the next menu option
Switch 5 - Select the current menu option
Switch1 + Switch4 – Changes the mode to user mode.

C. Specifications

Screening Audiometer SA.IITB-06

1. Tone frequencies: 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz
2. Levels
    a. For speaker: 0 dBHL, 20 dBHL, 40 dBHL, 60 dBHL
    b. For headphone: 0 dBHL, 20 dBHL, 40 dBHL, 60 dBHL, 80 dBHL
3. Internal Supplies: 5 V (104 mA), -5 V (70 mA), and 3 V.
4. Power Input: 230 V ac 50 Hz (mA)

D. Full circuit diagram

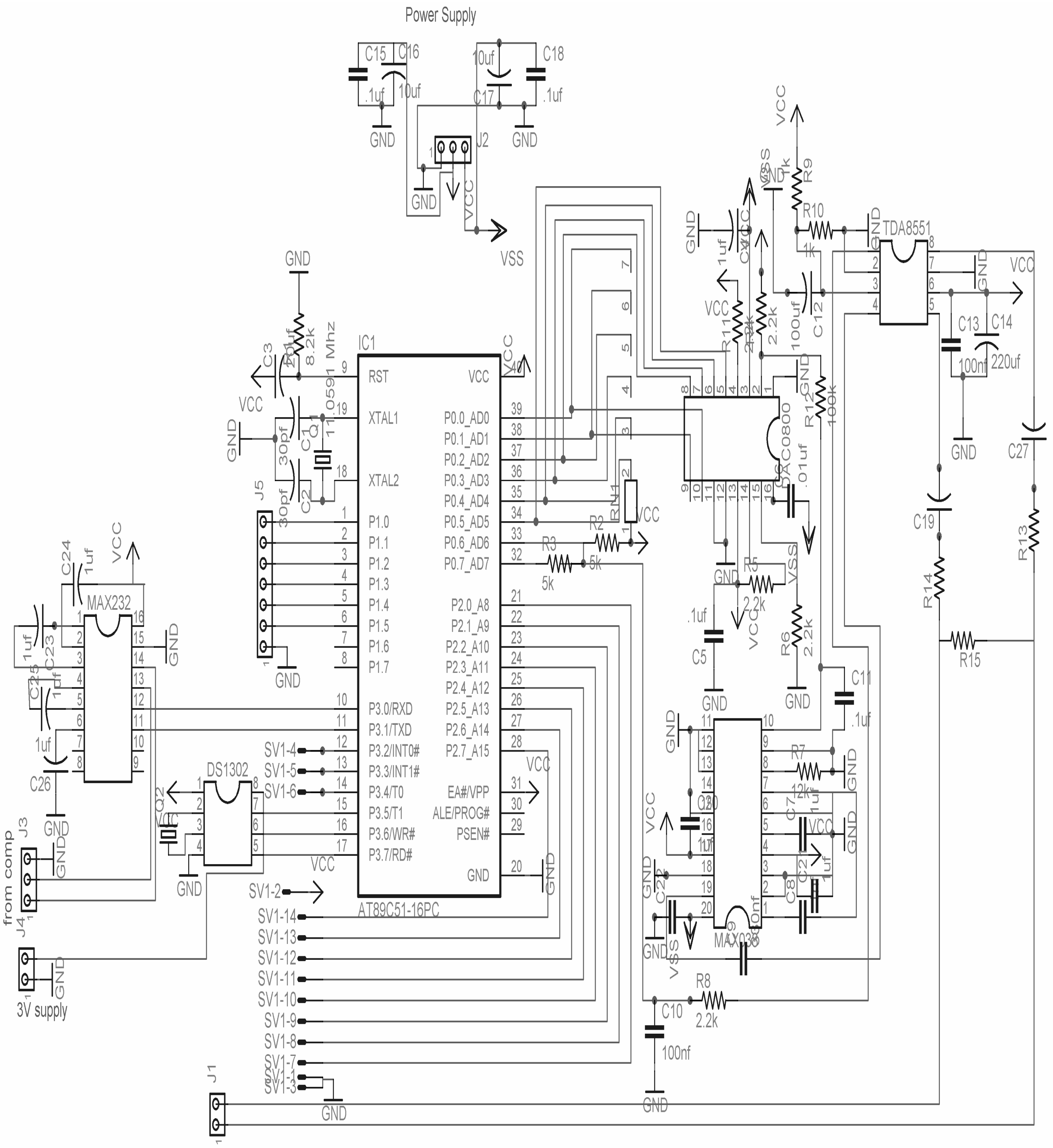

Figure A: Full circuit diagram of the audiometer