

Massachusetts Institute of Technology  
Department of Electrical Engineering and Computer Science

6.002 – Electronic Circuits  
Spring 2007

Lab 4: Audio Playback System

**Introduction**

In this lab, you will construct, test and demonstrate the audio playback system which you designed in Homework #11. The lab consists of two parts: Pre-lab exercises and in-lab exercises; there are no Post-lab exercises. You should complete the Pre-lab exercises in your lab notebook before coming to lab. Then, carry out the In-lab exercises between April 30 and May 11. After completing the In-lab exercises, have a TA check your work and sign your lab notebook. You may hand in your lab notebook for grading at that time.

**Before asking to get checked off, make sure you meet all the requirements in the checkoff list at the end of the In-Lab Exercises**

Note that in addition to regular lab hours from April 30 to May 4, there will be staff available in the lab the following week (May 7 through 11) for checkoff. You will be notified as to the times in lecture and by email.

**Reminder: You must complete all of the labs. Failure to do so will result in a deduction of one full grade in the class, no exceptions. Your lab notebook must be turned in with all Post-Labs completed and you must be checked off for all the labs.**

**Pre-Lab Exercises**

- (4-1) Copy your design for the clock from Problem 1 of Homework #11 into your lab notebook. Label all resistor and capacitor names and values.
- (4-2) Next to your design for the clock, copy the graph from Part (E) of Problem 1 of Homework #11 into your lab notebook. You will use this information to determine whether the clock you construct during In-Lab Exercise 4-2 works correctly.
- (4-3) Copy your design for the digital-to-analog converter from Problem 2 of Homework #11 into your lab notebook. Label all resistor names and values.
- (4-4) Next to your design for the digital-to-analog converter, make a table showing the expected converter output  $v_{\text{DAC}}$  when each of the data-bit input voltages is 5 V and the others are all 0 V. Base the table on the actual resistor values used in your design. Also, note the expected value of the offset voltage  $v_{\text{OFF}}$  required to center the converter. You will use this information to determine whether the converter you construct during In-Lab Exercise 4-4 works correctly.
- (4-5) Copy your design for the low-pass filter from Problem 3 of Homework #11 into your lab notebook. Label all resistor and capacitor names and values.

- (4-6) Next to your design for the low-pass filter, copy the graph from Part (F) of Problem 3 of Homework #11 into your lab notebook. Also, make a table showing the expected magnitude and phase of the filter output  $v_{\text{LPF}}$  given a 2-V peak-to-peak sinusoidal input with a frequency of 4 kHz, 8 kHz and 16 kHz. Base the table on the actual resistor and capacitor values used in your design. You will use this information to determine whether the filter you construct during In-Lab Exercise 4-6 works correctly.
- (4-7) Copy your design for the volume control stage from Problem 4 of Homework #11 into your lab notebook. Label all resistor and capacitor names and values.
- (4-8) Next to your design for the volume control stage, make a table showing the expected magnitude and phase of the volume control stage output  $v_{\text{OUT}}$  given a 2-V peak-to-peak sinusoidal input with a frequency of 10 Hz, 100 Hz and 1 kHz. Base the table on the actual resistor and capacitor values used in your design. You will use this information to determine whether the amplifier you construct during In-Lab Exercise 4-8 works correctly.

## In-lab Exercises

The In-lab exercises involve constructing and testing the individual functional blocks of the audio playback system, and then demonstrating the operation of the system as a whole.

You will need to obtain the counter and memory printed circuit board (PCB) from the stock-room, along with a small speaker. Since there is a limited supply of circuit boards and speakers available, make sure you return the memory board and the speaker when you are not using them.

The in-lab exercises are organized so that you will construct and test one functional block at a time. As each block is found to work properly, you will connect it to those which already working. Consequently, you will alternately construct and test various parts of the audio playback system. **As you develop the system in this manner, it is essential that you turn off the power to the protoboard before you make modifications to your system, or begin any new construction. Also, check your wiring carefully before turning the power back on.** This will avoid damaging the components in the system, and save you considerable debugging time.

Finally, construct the functional blocks as compactly and neatly as possible. In this spirit, you should find it easiest to use the components to wire themselves together, rather than using extra wires. This will save you considerable construction time, as well as considerable debugging time.

- (4-1) If you are working in a group of two, you should attach your two protoboards together. This will simplify the circuit assembly by providing more wiring space. To minimize wiring in this lab, the counter and memory have already been assembled on a printed-circuit board. On the back of this board are pins that will plug into the protoboards in the Lab. Plug these pins into the protoboards so that each pin is inserted into a separate protoboard row. Further, locate the board so that there is considerable protoboard space on the side with the memory output data bits. This will make connection to the board easiest. For example, locating the board towards the lower left corner of the protoboard may prove best. The clock can then be constructed above the board, while the digital-to-analog converter, the low-pass filter and the buffer can be constructed to the right of the board.

Figure 1 shows the pin assignments for the printed circuit board. The pins for the eight memory output data bits as well as the clock, power and ground pins are on the right hand side. You should connect the power pin to the 5-V power supply on the protoboard, and the ground pin to ground on the protoboard.

- (4-2) Following your design from Pre-Lab Exercise 4-1, construct the clock using the 74HC14 inverter chip obtained earlier. Figure 2 shows the pin assignments for the inverter chip. Use any two of the inverters in the chip, and leave the others unconnected. Do not yet connect the clock output  $v_{CLK}$  to the clock input of the counter. Rather, use one channel of the oscilloscope to observe the oscillator output  $v_{OSC}$ , and trigger the oscilloscope from that channel. Use the other channel to observe  $v_{CAP}$  and the clock output  $v_{CLK}$ . Compare what you observe with the oscilloscope to the graph prepared during Pre-Lab Exercise 4-2 to determine whether or not the clock is functioning properly. In particular, the clock output  $v_{CLK}$  should remain between 0 V and 5 V so as not to damage the counter which it drives. Also test whether the output signal is around 8 kHz.
- (4-3) Provided that the clock functions properly, and most importantly that the clock output  $v_{CLK}$  remains within the range of 0 V to 5 V, connect the clock output to the clock input

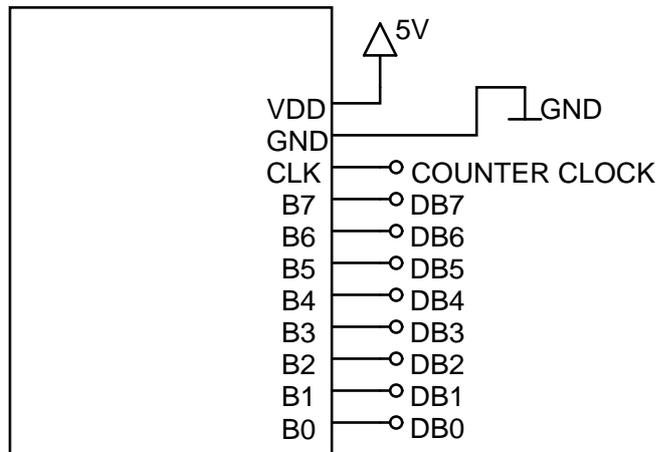


Figure 1: Pin assignments for the printed circuit board that contains the counter and memory.

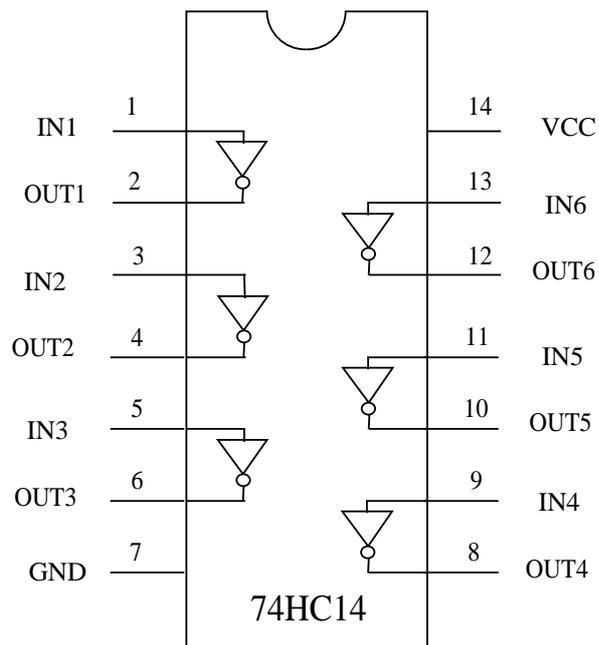


Figure 2: Pin assignments for the 74HC14 inverter chip.

of the counter. With the oscilloscope, verify that the eight data bits from the memory output are changing in time.

- (4-4) Following your design from Pre-Lab Exercise 4-3, construct the digital-to-analog converter using a 741 op-amp and the resistors in the package obtained earlier. Figure 3 shows the pin assignments for the 741 op-amp. Do not yet connect the converter data-bit inputs to the data-bit outputs from the memory. Rather, adjust the offset voltage  $v_{\text{OFF}}$  to 0 V, and connect each input individually to the 5-V power supply while leaving the other inputs grounded. Then, measure  $v_{\text{DAC}}$  with the multimeter, and compare the measurements to the data in the table prepared during Pre-Lab Exercise 4-4 to determine whether or not the converter is functioning properly.

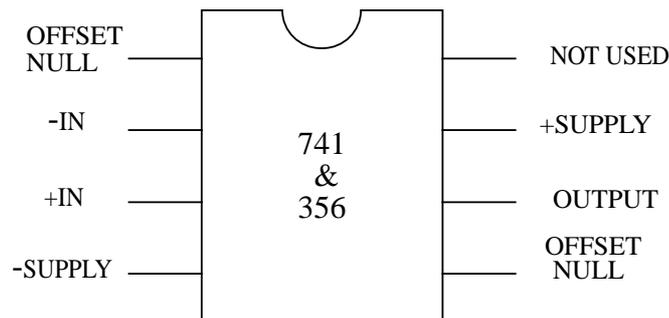


Figure 3: Pin assignments for the 741 op-amp.

- (4-5) Connect the eight data-bit inputs of the digital-to-analog converter to their corresponding data-bit outputs from the memory; refer to Figure 1 for the memory pin assignments. With the oscilloscope, observe the converter output  $v_{\text{DAC}}$ . You should see an audio signal reconstructed in a piecewise constant manner. Adjust the offset voltage  $v_{\text{OFF}}$  so that the audio signal is centered around 0 V.
- (4-6) Following your design from Pre-Lab Exercise 4-5, construct the low-pass filter using a 741 op-amp. Set the function generator to produce an unbiased 1-kHz sinusoid with a 2-V peak-to-peak amplitude and connect it to the input of the filter. With one channel of the oscilloscope, observe the input to the filter, and trigger the oscilloscope from that channel. With the other channel, observe the filter output  $v_{\text{LPF}}$ . Vary the frequency of its input voltage and compare the frequency response of the filter to that predicted by the graph and table prepared during Pre-Lab Exercise 4-6 to determine whether or not the filter is functioning properly.
- (4-7) Connect the output from the digital-to-analog converter to the input of the low-pass filter. Using the oscilloscope, compare the output from the converter to the output from the filter. While the two outputs should look similar, the output from the filter should look considerably smoother upon detailed inspection.

At this point, the peaks of the audio signal should be clearly observable with the oscilloscope at the low-pass filter output  $v_{\text{LPF}}$ . If necessary, adjust  $R_2$  in the digital-to-analog converter so that the peak-to-peak amplitude of the filter output,  $v_{\text{LPF}}$ , is approximately 2.5 V. This adjustment may be necessary if the audio signal was recorded with an insufficient gain. Also, adjust the offset voltage  $v_{\text{OFF}}$  in the converter again if the low-pass filter output  $v_{\text{LPF}}$  does not appear to be centered around 0 V.

- (4-8) Following your design from Pre-Lab Exercise 4-7, construct the volume control stage using a 741 op amp, but do not yet connect it to the speaker. Figure 3 shows the pin assignments for the op-amp. Set the function generator to produce an unbiased 1-kHz sinusoid with a 2-V peak-to-peak amplitude and connect it to the input of the buffer. With one channel of the oscilloscope, observe the input to the volume control stage, and trigger the oscilloscope from that channel. With the other channel, observe the volume control stage output  $v_{OUT}$ . Vary the frequency of its input voltage and compare the frequency response of the volume control stage to that predicted by the table prepared during Pre-Lab Exercise 4-8 to determine whether or not the volume control stage is functioning properly.
- (4-9) Next, connect the volume control stage to the speaker according to your design from Pre-Lab Exercise 4-7. Set the function generator to produce an unbiased 1-kHz sinusoid with a 2.5-V peak-to-peak amplitude and connect it to the input of the volume control stage. You should now hear a single-harmonic tone. Sweep the frequency of the signal generator over the range of 10 Hz to 10 kHz and use the oscilloscope to again demonstrate that the volume control stage is working properly.
- (4-10) Complete the audio playback system by connecting the output of the low-pass filter directly to the input of the volume control stage. You would now hear the audio signal recorded in the memory as it is played back through the speaker.
- (4-11) **OPTIONAL:** Experiment with the audio playback system. For example, remove the low-pass filter and see how your perception of the audio signal changes. Also, disconnect one or more of the least significant memory data bits from the digital-to-analog converter and see how your perception of the audio signal changes. Try this with and without the low-pass filter. How many data bits are necessary to make the audio signal intelligible?

### Checkoff List - Make sure you have the following items

- (4-1) Completed Pre-Lab Exercises in your lab notebook.
- (4-2) Completed In-Lab measurements in your lab notebook. **Make sure you've read each section of the In-Lab Exercises to note what measurements must be taken.**
- (4-3) Working circuit from In-Lab Exercise 4-10.