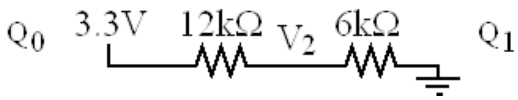
Example 13.1. Design a 2-bit binary-weighted DAC with a range of 0 to +3.3V using resistors.

Solution: We begin by specifying the desired input/output relationship of the 2-bit DAC. The design specifications are shown in Table 13.1.

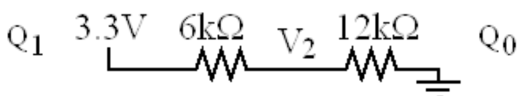
N	Q_1 Q_0	V_{out} (V)
0	`0   0`	0.0
1	`0   3.3`	1.1
2	`3.3 0`	2.2
3	`3.3 3.3`	3.3

Table 13.1. Specifications of the 2-bit binary-weighted DAC.

Assume the output high voltage (V_{OH}) of the microcontroller is 3.3 V, and its output low voltage (V_{OL}) is 0. With a binary-weighted DAC, we choose the resistor ratio to be 2/1 so Q_1 bit is twice as significant as the Q_0 bit, as shown in Figure 13.3. Considering the circuit on the left (no headphones), if both Q_1 and Q_0 are 0, the output V_{out} is zero. If Q_1 is 0 and Q_0 is +3.3V, the output V_{out} is determined by the resistor divider network



Note the total impedance from 3.3V to ground in the above circuit is 18kΩ. Using Ohm's Law, with the voltage divider equation, we can calculate V_{out} to be 3.3V*6kΩ/18kΩ, which is 1.1V. If Q_1 is +3.3V and Q_0 is 0, the output V_{out} is determined by the network



Again notice the total impedance from 3.3V to ground in this second circuit is 18kΩ. But this time we calculate V_{out} to be 3.3V*12kΩ/18kΩ, which is 2.2V. If both Q_1 and Q_0 are +3.3V, the output V_{out} is +3.3V. The output impedance of this DAC is approximately 12 kΩ, which means it cannot source or sink much current.

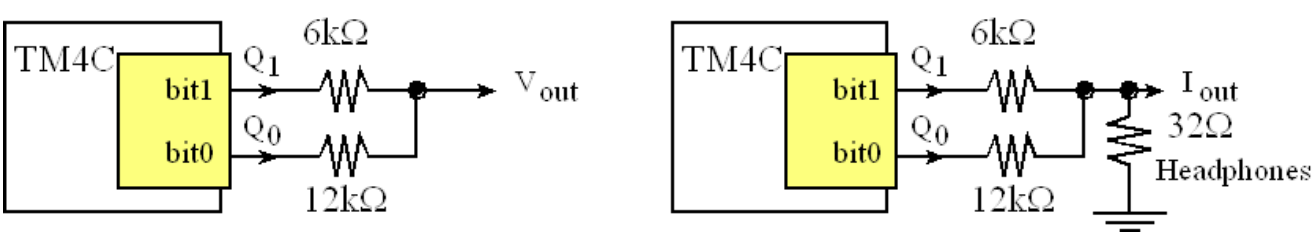


Figure 13.3. A 2-bit binary-weighted DAC.

If we connect headphones to this DAC, as shown in the right side of Figure 13.3, we could hear sounds generated by software writing a sequence of data to the DAC. However, since the impedance of the headphones is much smaller than the impedance of the DAC, the output voltages will be very small, but we could calculate the currents into the headphones. Considering the circuit on the right (with headphones), if both Q_1 and Q_0 are 0, the output current is zero. If Q_1 is 0 and Q_0 is +3.3V, the output current, I_{out}, is 3.3V divided by 12.032kΩ which is 0.275mA. If Q_0 is 0 and Q_1 is +3.3V, the output current, I_{out}, is 3.3V divided by 6.032kΩ which is 0.550mA. And finally, if both Q_1 and Q_0 are 3,3V, I_{out} is the sum of 0.275+0.550 (Kirkhoff's Current Law), which is about 0.825mA. Notice the current into the headphones is linearly related to the digital value. In other words, digital values of 0,1,2,3 map to currents of 0,0.275,0.550,0.825mA.

To view an interactive about how to compute Vout, see the link:

http://users.ece.utexas.edu/~valvano/Volume1/E-Book/C13_DACSound.htm#ITool13.3 (http://users.ece.utexas.edu/~valvano/Volume1/E-Book/C13_DACSound.htm#ITool13.3)

You can realistically build a 6-bit DAC using the binary-weighted method. Notice than with a 6-bit DAC, the largest resistor is 64 times the smallest, so the relative accuracy needs to be better than 1 part in 64. 1% tolerance resistors have a relative accuracy of 1/100, which is good enough for the DAC to be monotonic as it crosses from 011111_2 to 100000_2.