Workshop Six - Digital-to-Analogue Conversion

Introduction

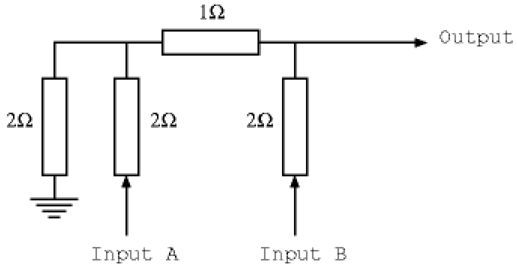
In this workshop, you will build two different kinds of digital-to-analogue converter (DAC). The first uses a resistor network called an R2R ladder, and works in parallel, i.e., a binary value is fed into the resistor network in parallel and a corresponding analogue signal is output. The second DAC (known as a 1-bit DAC) is all digital and uses a clock and a state machine to produce a single output. The output fed through an analogue low pass filter which removes the high frequency digital component leaving an average of the ones and zeros as the analogue output. The more ones that are in the sequence will cause the output voltage to rise, while the more zeros will cause the output voltage to fall.

Components

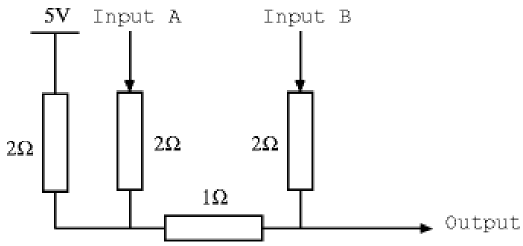
- 1a prototyping box
- 1 x 110Ω resistor
- 6 x 4k7Ω resistors
- 1 x 74HC283 adder
- 1 x 74HC374 octal D-type flip-flop
- 1 x 0.1µF capacitor
- 1 x light bulb and holder
- nMOS FET (ZVN3306A)
- Binary-coded rotary switch (optional)

Step 1: R2R ladder DAC

Task 1: Consider the following resistor network and answer questions 1 and 2.



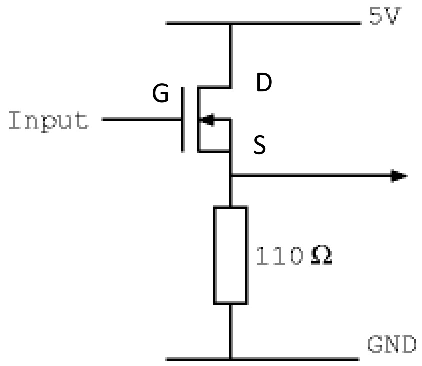
Task 2: Now consider the inverted version of this resistor network and answer question 1 again.



Step 2: Build the R2R DAC

Task 1: Construct the inverted DAC using 4.7kΩ resistors to replace the 2Ω resistors, and two 4.7kΩ resistors in parallel to replace the 1Ω resistors. Use the toggle switches as input and check that the output voltages are correct as the inputs are changed.

Task 2: Now connect an nMOS transistor and resistor load to form a voltage follower as shown in the following figure. Answer questions 3, 4 and 5.



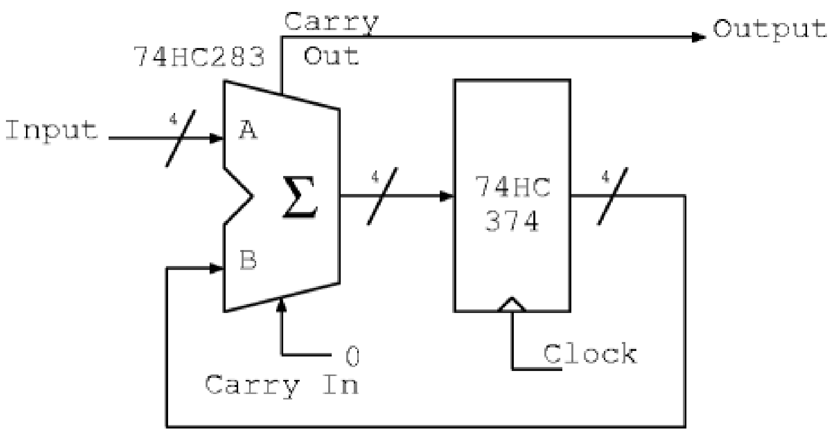
Voltage Follower Driving a 110Ω Load

Step 3: Build a 1-bit DAC (Bitstream DAC)

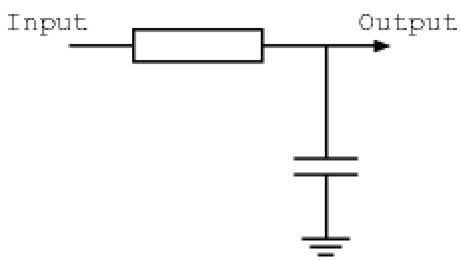
Use either four of the switches on the right-hand side of the breadboard or else the binary coded rotary switch to generate the desired input value.

Task 1: Consider the waveforms and answer question 6.

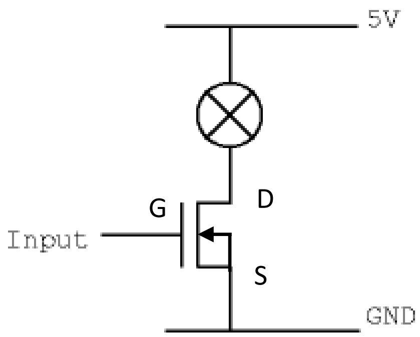
Task 2: Consider the circuit diagram below. The 74HC283 is a 4-bit adder with carry-in and carry-out. The 74HC374 contains 8 D-type flip-flops (although this circuit only uses 4 of them). Answer question 7. Construct this circuit and verify that it works.



Task 3: One way to convert this waveform into a steady voltage (the average voltage) is to filter the output through a low-pass filter. This will remove the high frequency component in the waveform. Set the clock to 100kHz, and try a resistor value of 4.7kΩ and a 0.1μF capacitor. Using an oscilloscope, verify that the output is filtered and corresponds to the binary input selected. Answer question 8.



Task 4: Replace the output filter with a light bulb and nMOS driver transistor as shown below. Since the temperature of the light bulb filament has inertia, it provides a filtering effect on the light output. Answer question 9.



Assessment

Ticking criteria: Write up your experimental data and answer the following questions.

Once your work has met the **Common Ticking Criteria** (see Introduction), get your work ticked by an assessor. Remember that you need to hand in this assessed exercise as part of your portfolio of work (see the Head of Department's notice).

Questions

1. Using Ohm's law and the formula for resistors in parallel, what is the output voltage of the R2R DAC when inputs A and B are connected to each combination of ground and 5 volts? Please display the results as a table.
2. How much current will flow through this resistor network when input B is connected to 5 volts and A to ground?
3. How much current flows through the load when the gate voltage is at its maximum? Give the values of two parameters of the circuit, apart from the supply voltage, that limits the current?
4. Why is it a good idea to use a voltage follower on the output of the R2R DAC resistor network?
5. Why is the inverted version of the R2R DAC used with the voltage follower rather than using the non-inverted form?
6. What is the long-term average voltage of each of the 1-bit DAC waveforms?
7. For the 1-bit DAC, if the input has a fixed value 7 (0111 in binary), and the flip-flops all start at zero, what values do the flip-flops attain in the next 16 clock cycles and what value does carry-out take in each cycle?
8. If you were going to design a 16-bit DAC for audio purposes (e.g. CD player output), how would the resistor tolerances affect the errors in the output for R2R and 1-bit DAC implementations?
9. How does the power efficiency of the R2R DAC with voltage follower compare with the 1-bit DAC with driver transistor?

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