National Aviation University

Department of Electronics, Robotics, Monitoring and IoT Technologies

Course: “Analog and Digital Instrumentation”

Experiment 6

“Digital to analog converter using *R*-2*R* ladder”

«Цифро-аналоговий перетворювач з використанням резистивної матриці R-2R»

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LEARNING OBJECTIVE

- To observe and measure the performance of a 4-bit R-2R digital to analogue converter.

Introduction

A digital to analogue converter (DAC) is a device that outputs a voltage proportional to an input binary number. Such a device is frequently required in applications where a digital computer must generate a signal that has an influence on the 'real' world. Real world signals are continuously variable – i.e., analogue signals – whereas signals within a computer have a finite number of values – i.e., discrete signals. A DAC is used to perform the necessary conversion. Figure 1 shows the basic arrangement of a DAC using an *R*-2*R* ladder.

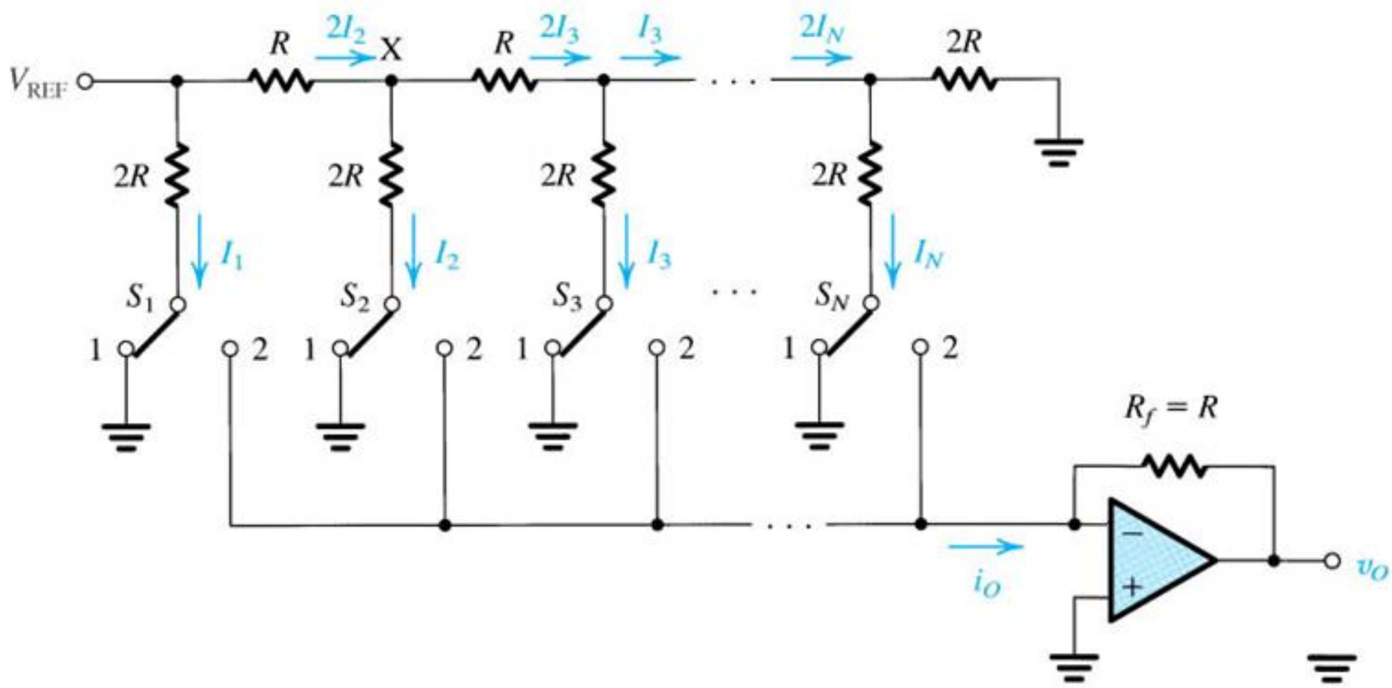


Figure 1: The basic circuit configuration of a DAC utilizing an *R*-2*R* ladder network

Because of the small difference in resistance values, this network is usually preferred to the binary-weighted scheme, especially for $N > 4$. Operation of the *R*-2*R* ladder is straightforward. First, it can be shown, by starting from the right and working toward the left, that the resistance to the right of each ladder node, such as that labeled **X**, is equal to 2*R*. Thus the current flowing to the right, away from each node, is equal to the current flowing downward to ground, and twice that current which flows into the node from the left side. It follows that

$$I_1 = 2I_2 = 4I_3 = ... = 2^{N-1} \times I_N$$

Thus, as in the binary-weighted resistive network, the currents controlled by the switches are binary weighted (*Таким чином, як і в резистивному ланцюгу з двійковим зважуванням, струми, керовані перемикачами, зважуються двійково*).

The output current i_O will therefore be given by

$$i_O = \frac{V_{REF}}{2R} b_1 + \frac{V_{REF}}{2R \times 2} b_2 + \ldots + \frac{V_{REF}}{2R \times 2^{N-1}} = \frac{V_{\mathrm{REF}}}{R}\left(\frac{b_1}{2^1} + \frac{b_2}{2^2} + \ldots + \frac{b_N}{2^N}\right) = \frac{V_{\mathrm{REF}}}{R} D \qquad (1)$$

where D is the digital word.

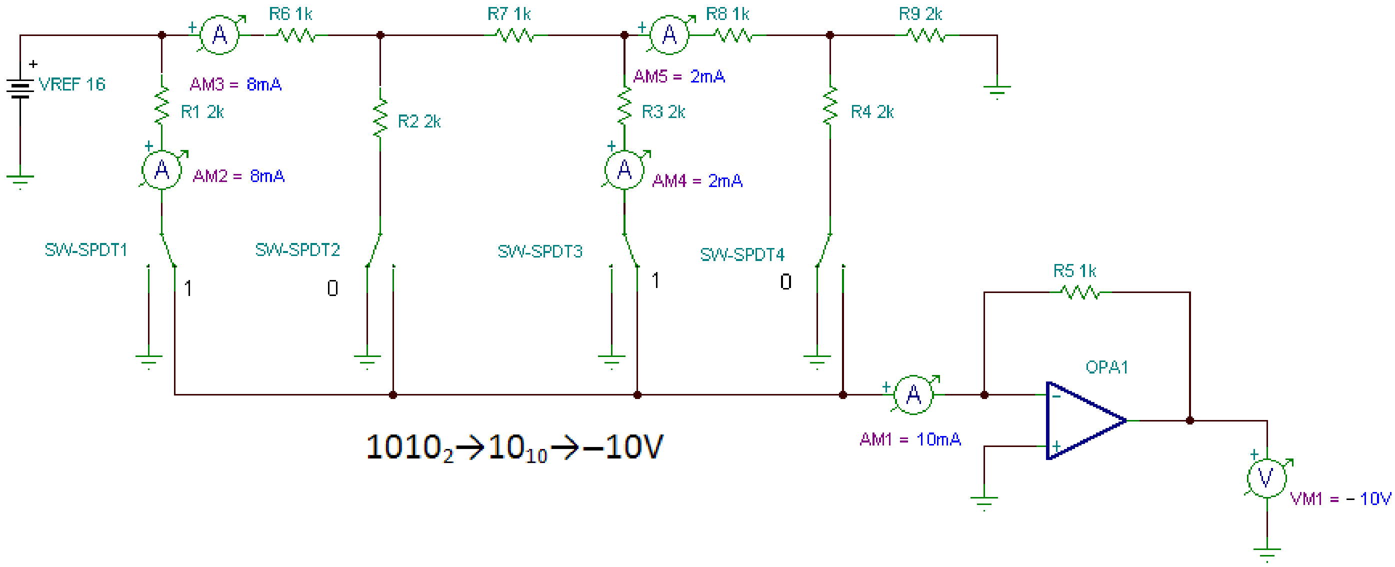
And the output voltage v_O is determined as

$$v_O = -i_O R \qquad (2)$$

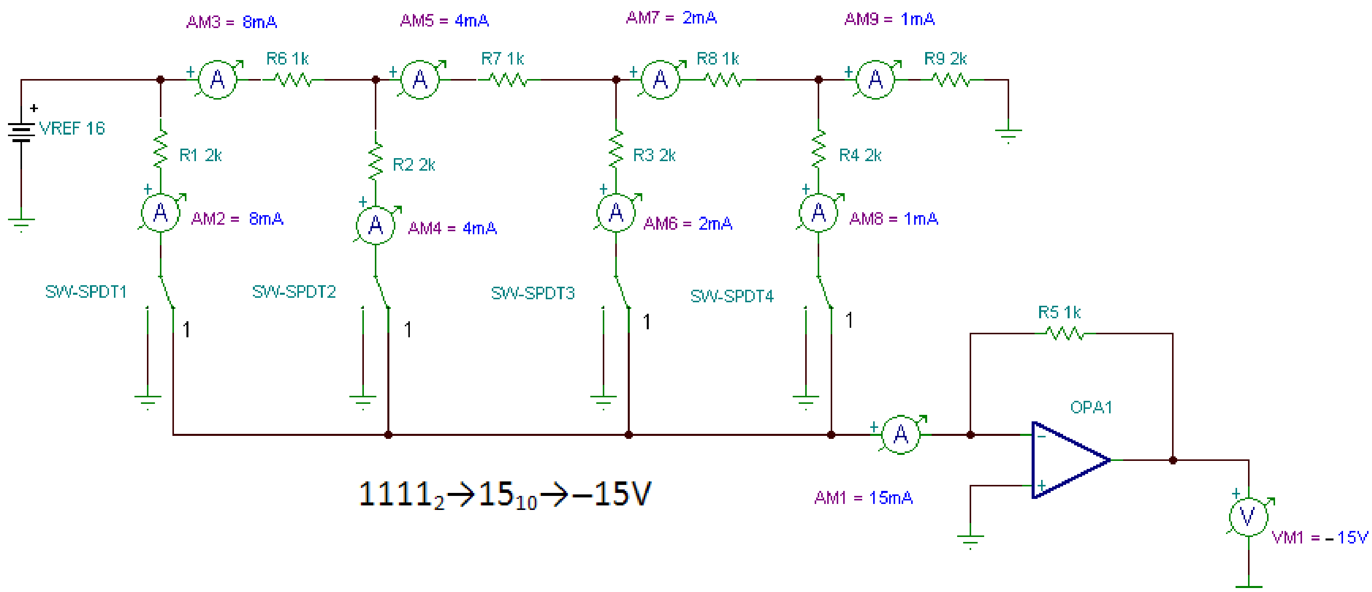
The circuit of Fig. 1 was simulated for two binary words $1010_2 = 10_{10}$ and $1111_2 = 15$ as shown in Fig. 2. Using Equations (1) and (2) we find for the binary word 1010_2

$$i_O = \frac{V_{\mathrm{REF}}}{R}\left(\frac{b_1}{2^1} + \frac{b_2}{2^2} + \ldots + \frac{b_N}{2^N}\right) = \frac{16}{1\mathrm{k}\Omega}\left(\frac{1}{2^1} + \frac{0}{2^2} + \frac{1}{2^3} + \frac{0}{2^4}\right) = 10\mathrm{mA}$$

$$v_O = -i_O R = -(10\mathrm{mA}) \times (1\mathrm{k}\Omega) = -10\mathrm{V}$$



(a)



(b)

Figure 2: Simulation of the 4-bit DAC using an *R*-2*R* ladder network

Analogically, we calculate i_O and v_O for the digital word 1111_2

$$i_O = \frac{V_{\text{REF}}}{R}\left(\frac{b_1}{2^1}+\frac{b_2}{2^2}+\ldots+\frac{b_N}{2^N}\right)=\frac{16}{1\text{k}\Omega}\left(\frac{1}{2^1}+\frac{1}{2^2}+\frac{1}{2^3}+\frac{1}{2^4}\right)=15\text{mA}$$

$$v_O = -i_O R = -(15\text{mA})\times(1\text{k}\Omega) = -15\text{V}$$

As seen from Fig. 2, the simulated DAC circuit has the same voltages and currents as those calculated by Equations (1) and (22).

EQUIPMENT

1. Digital multimeter Agilent 34401A
2. Solderless breadboard BB830T
3. Two power supplies: ± 18V.
4. Power supply 16 V.
5. Resistors: 4 × 1.0 kΩ, 5 × 2.0 kΩ
6. 741 operational amplifier.

PROCEDURE

The pin connections for the 8 pin DIP package uA741 op-amp are given in Fig. 3. Throughout this experiment use the external DC Power Supplies with **+18V**, **0**, **-18V** jacks. The initial location of the uA741 chip and connections to +18V, 0, -18V terminals of the power supply are shown in Fig. 4.

To use the Power Supplies:

• Turn the Power Supplies ON. This will set both positive and negative power sources respectively to **+18V** and **–18V**. Measure these voltages with digital multemeter.

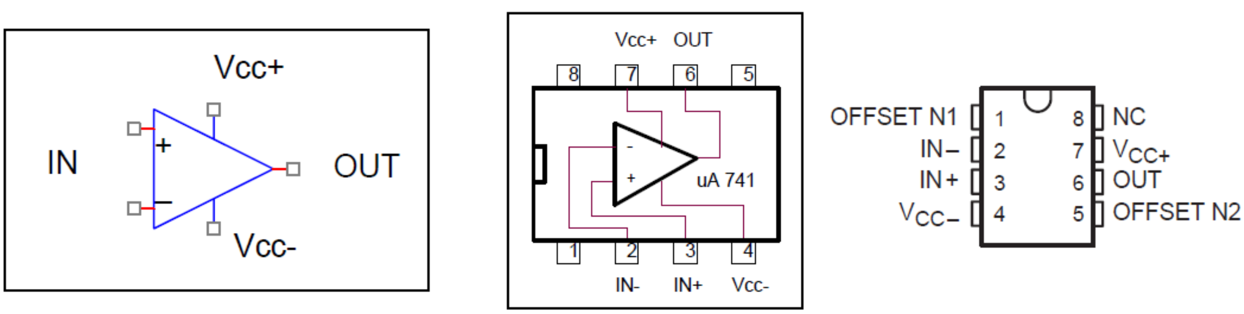


Figure 3: Symbol for a basic op-amp (a), the μA741 op-amp package (b)

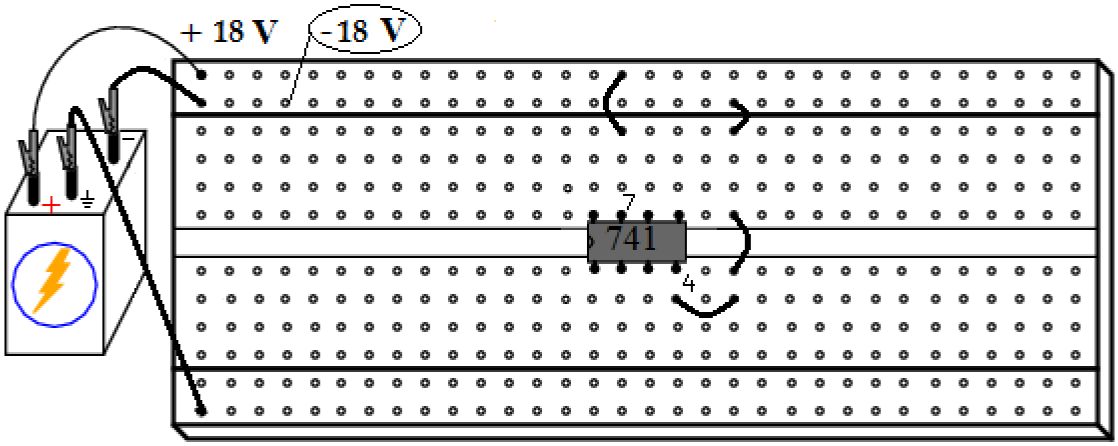


Figure 4: Initial location of uA741 chip on the solderless breadboard

• Turn the Power Supplies OFF before connecting to the circuits.

• Connect the **+18V** terminal of the Power Supply to the V_{CC}^{+} of your circuit as shown in Fig. 4. Connect the **-18V** terminal of the Power Supply to the V_{CC}^{-} of your circuit as shown in Fig. 4. Connect the **COM** terminal of the Power Supplies to the ground of your circuit as shown in Fig. 4.

1. Build the circuit with R = 1.0 kΩ and 2R = 2.0 kΩ. Use wire links for D0-D3 to allow switching between LOW and HIGH.
2. Set V_{REF} to **16** volts.
3. Apply power to the circuit by turning on the ±18 V power supplies.
4. For each given switch combination, measure and record the output voltage V_o.
5. Plot the results on the graph sheet.
6. Calculate the maximum % linearity error for the DAC from the plotted results.

$E\% = 100\% \times (V_{\text{theoretical}} - V_{\text{measured}}) / V_{\text{theoretical}}$

7. Comment on the measured behaviour of the DAC compared to ideal behaviour.

REFERENCE

1. A.S. Sedra and K.S. Smith, "Microelectronic circuits", 5th ed., New York: Oxford University Press, 2004, 1283 p.