

## (5) D/A CONVERTERS

### 1. OBJECTIVES

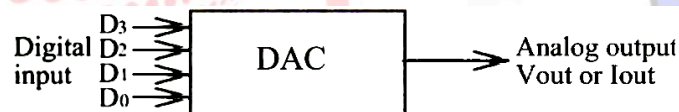
- (1) Understanding the operation of a digital-to-analog converter.
- (2) Understanding the operation of DAC0800.
- (3) Studying how to generate unipolar and bipolar outputs using DAC0800.

### 2. DISCUSSION OF FUNDAMENTALS

The digital-to-analog converters (DAC's or D/A converters) are used in transforming the digital signals of transmitted data, stored on media, or the results of computation back to analog signals for control, information display, or further analog processing.

#### DAC Operation

In short, D/A converters are the devices by which digital systems communicate with outside world. A DAC converts digital input states to analog output voltages or currents. The schematic symbol of a 4-bit DAC is shown in Figure 5-1(a).



(a) Schematic symbol

D <sub>3</sub>	D <sub>2</sub>	D <sub>1</sub>	D <sub>0</sub>	V <sub>out</sub>	D <sub>3</sub>	D <sub>2</sub>	D <sub>1</sub>	D <sub>0</sub>	V <sub>out</sub>
0	0	0	0	0	1	0	0	0	8
0	0	0	1	1	1	0	0	1	9
0	0	1	0	2	1	0	1	0	10
0	0	1	1	3	1	0	1	1	11
0	1	0	0	4	1	1	0	0	12
0	1	0	1	5	1	1	0	1	13
0	1	1	0	6	1	1	1	0	14
0	1	1	1	7	1	1	1	1	15

(b) Truth table

Figure 5-1 Fig 10-1 4-bit DAC

The digital inputs D<sub>3</sub>, D<sub>2</sub>, D<sub>1</sub> and D<sub>0</sub> are usually driven by the register output of a digital system. Figure 5-1(b) shows the truth table of the 4-bit DAC. Each input binary word produces a single, discrete analog output value. Over the output range of the converter, 2<sup>4</sup> or 16 different voltage values are produced including zero, and the output has a one-to-one correspondence with input.

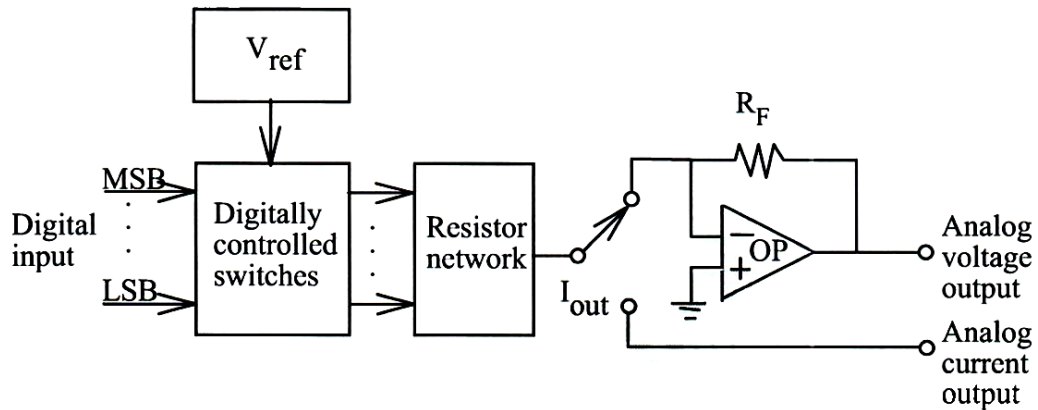


Figure 5-2 DAC block diagram

Figure 5-2 provides a DAC block diagram. The DAC includes a precision reference voltage source, digitally controlled switches, resistor network, and an OP AMP. Each resistor in resistor network is connected to a digitally controlled switch, which connect the resistor to the reference voltage  $V_{ref}$ . The other end of each resistor is connected to the summing point of OP AMP. The digital input states determine the states of switches and the OP AMP converts the DAC output current  $I_{out}$  to the output voltage  $V_{out}$ .

Resistor network is the major configuration of DAC circuit. There are two popular types: weighted-resistor network and R-2R ladder resistor network. The weighted-resistor method can be considered that the value of each summing resistor is inversely proportional to the weight of the digital bit actuating the series switch. The weighted-resistor technique has the advantages of simplicity and high speed. A difficulty in implementing higher resolution DAC designs is that a wide range of resistors is required, and very high value resistors cause problems with both temperature stability and switching speed. If the resistors were to be manufactured in integrated circuit (IC) form, such a range would be totally impractical. The advantage of the R-2R ladder method is that only two values (R and 2R) of resistors are required, with the resultant ease of matching or trimming.

Figure 5-3 shows a 4-bit R-2R ladder DAC circuit. The resistor network consists of series resistors of R and shunt resistors of 2R. Observation of the R-2R ladder configuration reveals that at any of points A, B, C, and D the resistance is 2R looking to the right; therefore, the reference input to the ladder has a resistance of R. According to this property, the output current can be derived from the following:

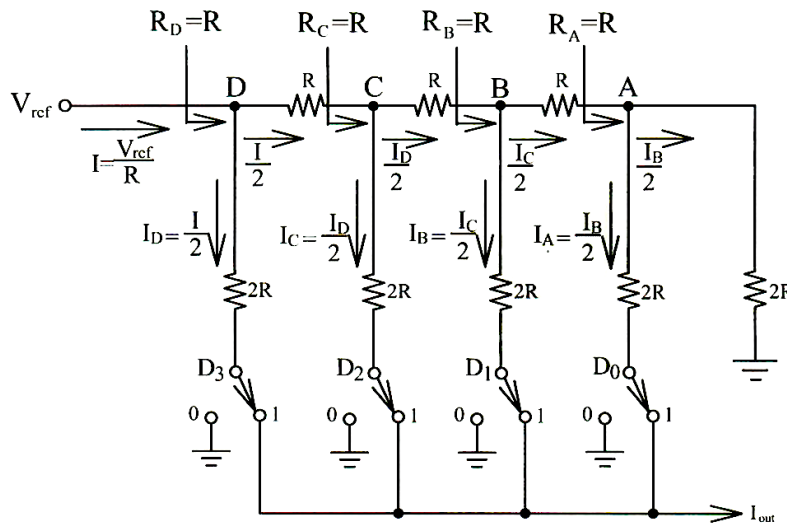


Figure 5-3 4-bit R-2R ladder DAC

$$I = V_{ref} / R$$

$$I_D = I / 2$$

$$I_C = I_D / 2 = I / 4$$

$$I_B = I_C / 2 = I / 8$$

$$I_A = I_B / 2 = I / 16$$

$$I_{out} = I_D + I_C + I_B + I_A = I \left( \frac{D_3}{2} + \frac{D_2}{4} + \frac{D_1}{8} + \frac{D_0}{16} \right)$$

where D3, D2, D1 and D0 may be either "1" or "0" depended on the positions of switches.

### Input Weight

For a DAC each digital input bit has its own weight which is the analog output value when the bit is 1. Consider the 4-bit DAC of Figure 5-1(a). If D0 = 1 and D1 = D2 = D3 = 0, the analog output value of 1V is the weight of D0. Similarly, the weights of D2 and D3 are 2V, 4V and 8V, respectively. To obtain the resultant analog output, it is simple by adding these weights up. For example, the analog output voltage Vout should be 4+2+1= 7V for the digital input 0111.

### Resolution and Step Value

The resolution of DAC is defined as the smallest difference of the analog output when the digital input changes a unit count. It is usually an LSB weight. Referring to Figure 5-1(b), the  $V_{out}$  increases an analog value of 1 V for each unit count fed to the digital input. Thus, the resolution of this DAC is 1V.

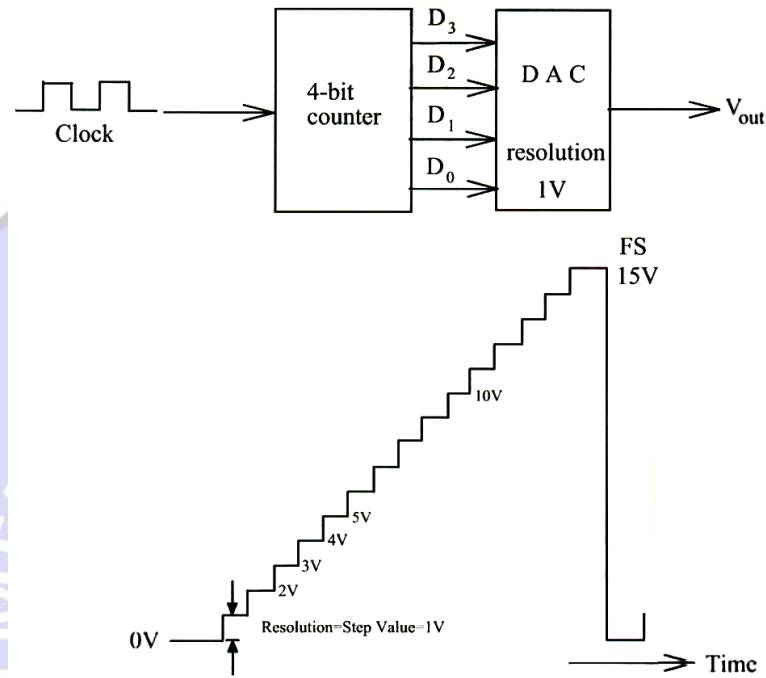


Figure 5-4 Staircase-ramp DAC

The resolution is also called the step value or the step height. Consider the 4-bit staircase-ramp DAC shown in Figure 5-4. The output voltage increases by 1V for each unit count fed to the input. The output difference between steps, called the step height, is exactly 1V.

### DAC 0800 Digital-to-Analog Converter

The DAC 0800 is an inexpensive monolithic 8-bit DAC including the reference voltage source, R-2R ladder and transistor switches. Figure 5-5 shows the pin configuration of DAC0800.

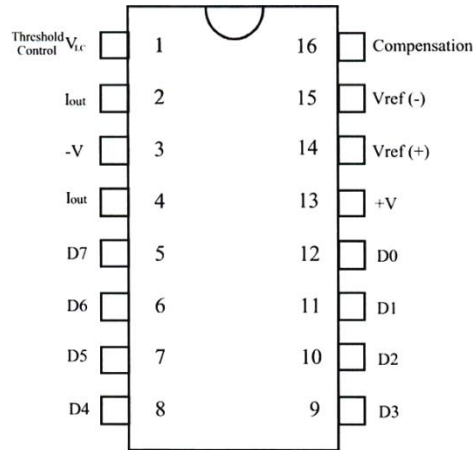


Figure 5-5 DAC 0800 pin configuration

Power supply requirements of the DAC0800 are  $\pm 4.5$  V to  $\pm 18$  V. Power dissipation is 33mW with  $\pm 5$  VDC power supplies and the settling time is about 85 nS. With complementary current outputs  $I_{out}$  (pin 4) and  $\overline{I_{out}}$  (pin 2), the DAC0800 can be used in either unipolar or bipolar output.

Figure 5-6 shows the unipolar voltage output DAC using the DAC0800 with  $\mu A741$ . The  $V_{ref(-)}$  pin is grounded through the resistor R2. The positive reference source +5 V is applied to  $V_{ref(+)}$  pin through series resistor R1. Therefore, the reference current  $I_{ref}$  flowing through  $R_i$  is found to be

$$I_{ref} = \frac{V_{ref}}{R_1} \quad (10-1)$$

The output current  $I_{out}$  is

$$I_{out} \approx \frac{V_{ref}}{R_1} \left( \frac{D_7}{2} + \frac{D_6}{4} + \frac{D_5}{8} + \frac{D_4}{16} + \frac{D_3}{32} + \frac{D_2}{64} + \frac{D_1}{128} + \frac{D_0}{256} \right) \quad (10-2)$$

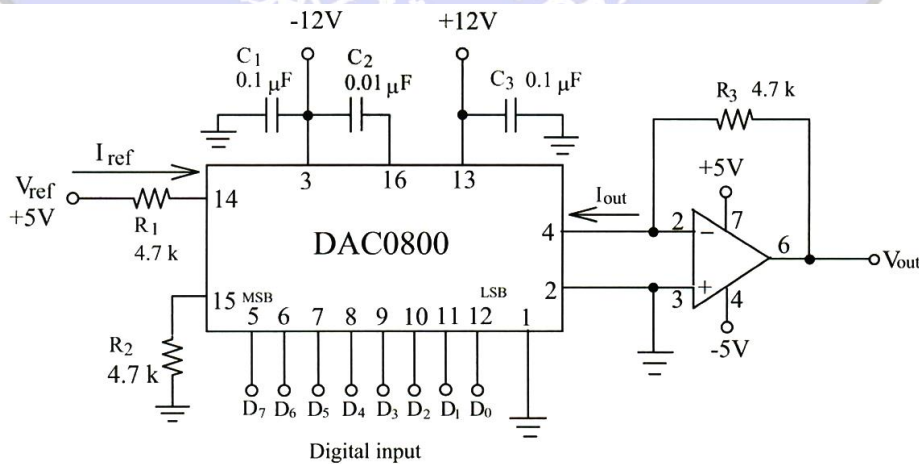


Figure 5-6 DAC0800 unipolar voltage output circuit

This  $I_{out}$ , the current flowing out of the converter, is then converted to an output voltage by the  $\mu A741$ . The voltage output  $V_{out}$  can be given by

$$V_{out} = I_{out}R_3 \quad (10-3)$$

The bipolar voltage output circuit of DAC0800 is shown in Figure 5-7. The  $\overline{I_{out}}$  pin is connected to the noninverting input of  $\mu A741$  instead of to ground in Figure 5-6. Thus, the  $\mu A741$  output voltage can be evaluated by

$$V_{out} = (I_{out} - \overline{I_{out}})R_4 \quad (10-4)$$

where  $I_{out}$  and  $\overline{I_{out}}$  are complementary current outputs. By definition, the full scale current can be expressed as  $I_{FS} = I_{out} + \overline{I_{out}}$ , and the  $\overline{I_{out}}$  is

$$\overline{I_{out}} = I_{FS} - I_{out} \quad (10-5)$$

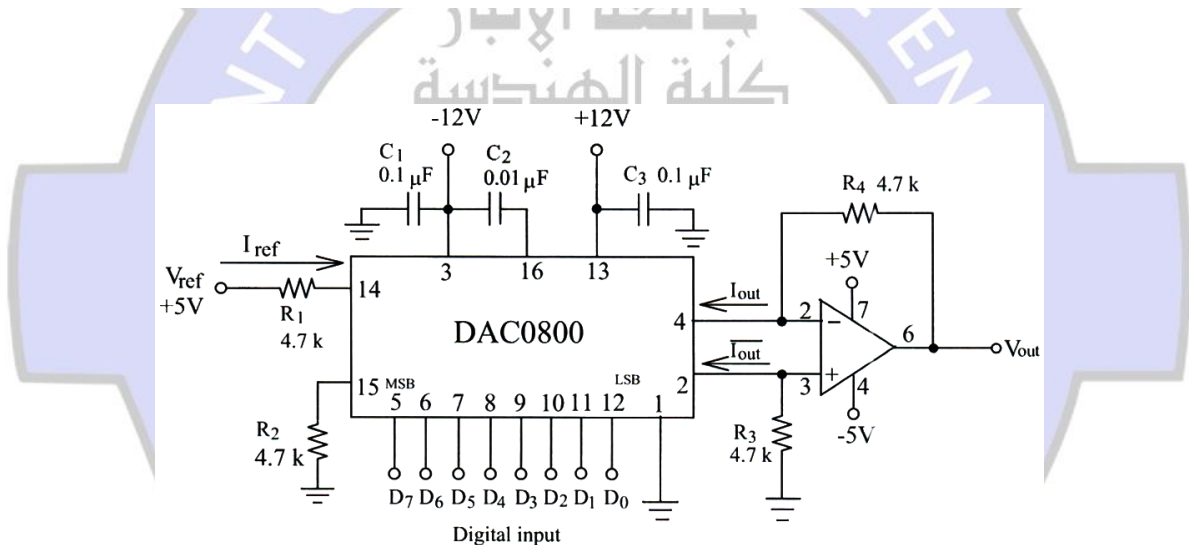


Figure 5-7 DAC0800 bipolar voltage output circuit

Substituting Eq. (10-5) into Eq. (10-4), we obtain

$$V_{out} = 2I_{out}R_4 - I_{FS}R_4 \quad (10-6)$$

### 3. EQUIPMENT REQUIRED

- (1) Module KL-96001
- (2) Module KL-94001
- (3) DMM

#### 4. EXPERIMENTS AND RECORDS

##### Experiment 10-1 DAC0800 Unipolar Voltage Output

- (1) Locate DAC0800 Unipolar Digital-to-Analog Converter circuit on Module KL-94001. Insert the connect plug in J1 to connect the DAC0800 output  $I_{out}$  (pin 4) to the  $\mu A741$  input (pin 2).
- (2) Calculate and record the step value in Table 5-1.
- (3) Set input switches D0 through D7 to correct positions 0000 0000. ("0" = GND; "1" = +5 V)
- (4) Using Eqs. (10-2) and (10-3), calculate and record the output current  $I_{out}$  and output voltage  $V_{out}$  in Table 5-1.
- (5) Remove the connect plug from J1. Measure the  $I_{out}$  by connecting the DMM current meter between DAC0800 output and  $\mu A741$  input. Record the result in Table 5-1.
- (6) Remove the DMM and reinsert the connect plug in J1. Measure the output voltage  $V_{out}$  at  $\mu A741$  output (O/P) using the DMM voltmeter and record the result in Table 5-1.
- (7) Following the digital codes listed in Table 5-1, change the switches D7 to D0 and repeat steps 5 and 6 sequentially. Record the results in Table 5-1.

##### Experiment 10-2 DAC0800 Bipolar Voltage Output

- (1) Locate DAC0800 Bipolar Digital-to-Analog Converter on Module KL-94001. Insert connect plugs in J1 and J2.
- (2) Calculate and record the step value in Table 5-2.
- (3) Set input switches D0 through D7 to correct positions 0000 0000. ("0" = GND; "1" = +5 V)
- (4) Using Eqs. (10-2) and (10-6), calculate and record the values of  $V_{out}$  in Table 5-2.
- (5) Using the DMM, measure the output voltage  $V_{out}$  and record the result in Table 5-2.
- (6) Remove the connect plug from J1. Measure the output current  $I_{out}$  by connecting the DMM in J1 and record the result in Table 5-2.
- (7) Remove the connect plug from J2 and insert it in J1. Measure the output current  $\overline{I_{out}}$  by connecting the DMM in J2 and record the result in Table 5-2.
- (8) Calculate the value of  $I_{out} + \overline{I_{out}}$  and record the result in Table 5-2.
- (9) Following the digital codes listed in Table 5-2, change the switches D7 to D0 and repeat steps 5 through 8 sequentially. Record the results in Table 5-2.

Table 5-1

Step Value = \_\_\_\_\_

Digital Input								Analog Output			
D <sub>7</sub>	D <sub>6</sub>	D <sub>5</sub>	D <sub>4</sub>	D <sub>3</sub>	D <sub>2</sub>	D <sub>1</sub>	D <sub>0</sub>	V <sub>out</sub>		I <sub>out</sub>	
								Calculated	Measured	Calculated	Measured
0	0	0	0	0	0	0	0				
0	0	0	0	0	0	0	1				
0	0	0	0	0	0	1	0				
0	0	0	0	0	1	0	0				
0	0	0	0	1	0	0	0				
0	0	0	1	0	0	0	0				
0	0	1	0	0	0	0	0				
0	1	0	0	0	0	0	0				
1	0	0	0	0	0	0	0				
1	1	1	1	1	1	1	1				

Voltage in V

Current in mA





Table 5-2

Step Value = \_\_\_\_\_

Digital Input								Analog Output				
D <sub>7</sub>	D <sub>6</sub>	D <sub>5</sub>	D <sub>4</sub>	D <sub>3</sub>	D <sub>2</sub>	D <sub>1</sub>	D <sub>0</sub>	Calculated	Measured Value			
								V <sub>out</sub>	V <sub>out</sub>	I <sub>out</sub>	$\overline{I_{out}}$	I <sub>out</sub> + $\overline{I_{out}}$
0	0	0	0	0	0	0	0					
0	0	0	0	0	0	1	0					
0	0	0	0	1	0	0	0					
0	0	1	0	0	0	0	0					
0	1	1	1	1	1	1	1					
1	0	0	0	0	0	0	0					
1	0	0	0	0	0	1	0					
1	0	0	0	1	0	0	0					
1	0	1	0	0	0	0	0					
1	1	0	0	0	0	0	0					
1	1	1	1	1	1	1	1					

Voltage in V

Current in mA

### 5. QUESTIONS

- (1) In Figure 5-6, if the digital inputs are 01101010, calculate the output voltage by the weight of bit.
- (2) From a point of view of the step size or the output range, compare the unipolar output with the bipolar output.
- (3) According to the results of Table 5-2, comment on the relationship between  $I_{out}$  and  $\overline{I_{out}}$ .