Chapter 10

D/A CONVERTERS

10.1 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.

10.2 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 Fig. 10-1(a).

(a) Schematic symbol

D_3	D_2	D_1	D_0	V_{out}	D_3	D_2	D_1	D_0	V_{out}
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

Fig.10-1 4-bit DAC

The digital inputs D_3, D_2, D_1 and D_0 are usually driven by the register output of a digital system. Fig. 10-1(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, 2^4 or 16 different voltage values are produced including zero, and the output has a one-to-one correspondence with input.

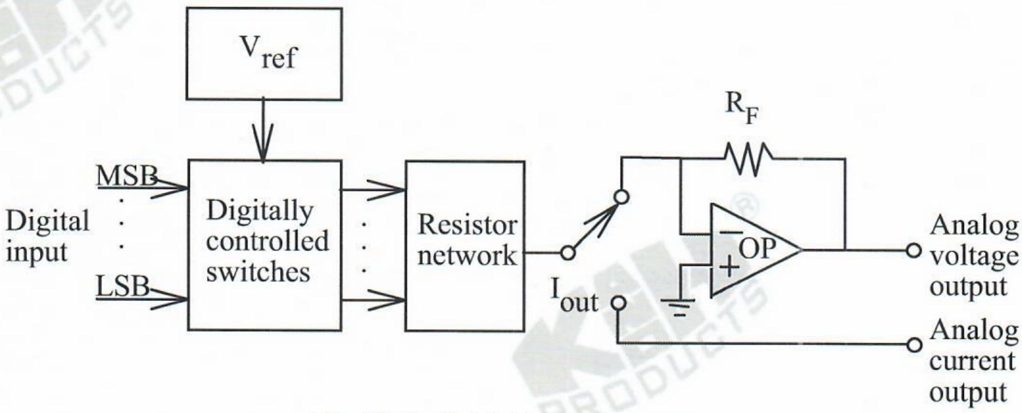

Fig.10-2 DAC block diagram

Fig. 10-2 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.

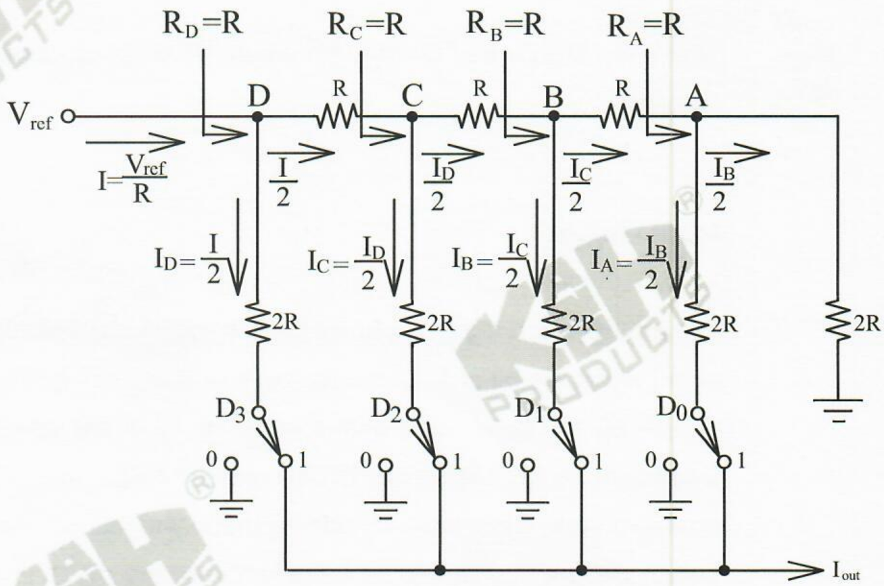

Fig.10-3 4-bit R-2R ladder DAC

Fig. 10-3 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:

$I = Vref / R$

$I_D = I / 2$

$I_C = I_D / 2 = I / 4$

$I_B = I_C / 2 = I / 8$

$I_A = I_B / 2 = I / 16$

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

where D_3, D_2, D_1 and D_0 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 Fig. 10-1(a). If $D_0 = 1$ and $D_1 = D_2 = D_3 = 0$, the analog output value of 1V is the weight of D_0. Similarly, the weights of D_1, D_2 and D_3 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 V_{out} 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 a LSB weight. Referring to Fig. 10-1(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.

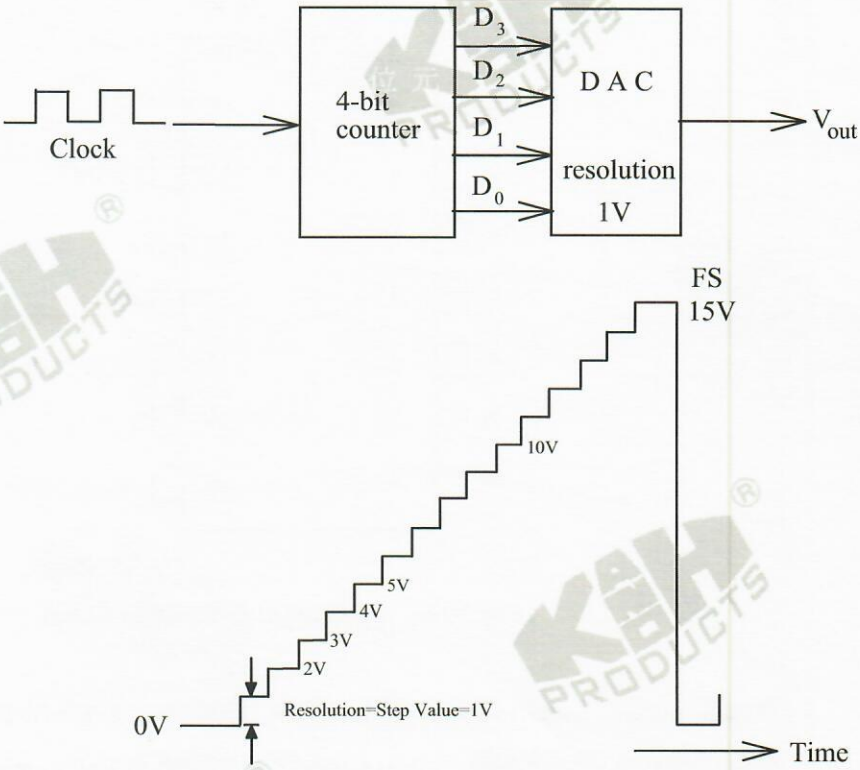

Fig.10-4 Staircase-ramp DAC

The resolution is also called the step value or the step height. Consider the 4-bit staircase-ramp DAC shown in Fig. 10-4. 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. Fig.10-5 shows the pin configuration of DAC0800.

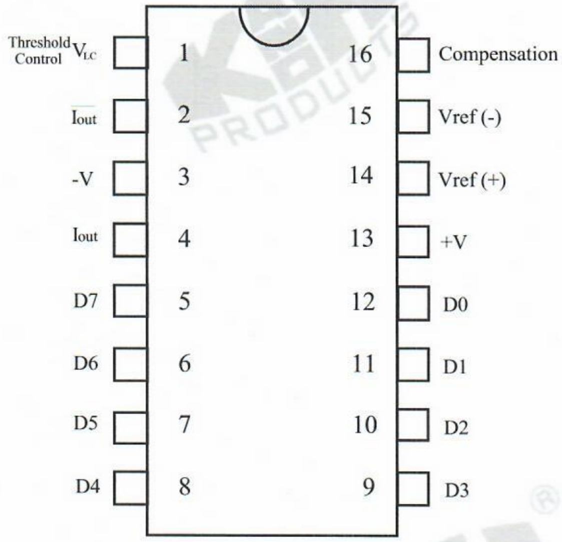

Fig.10-5 DAC 0800 pin configuration

Power supply requirements of the DAC0800 are ±4.5 V to ±18 V. Power dissipation is 33mW with ±5 V_{DC} 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.

Fig. 10-6 shows the unipolar voltage output DAC using the DAC0800 with μA741. The V_{ref}(-) pin is grounded through the resistor R_2. The positive reference source +5 V is applied to V_{ref}(+) pin through series resistor R_1 . Therefore the reference current I_{ref} flowing through R_1 is found to be

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

The output current I_{out} is

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

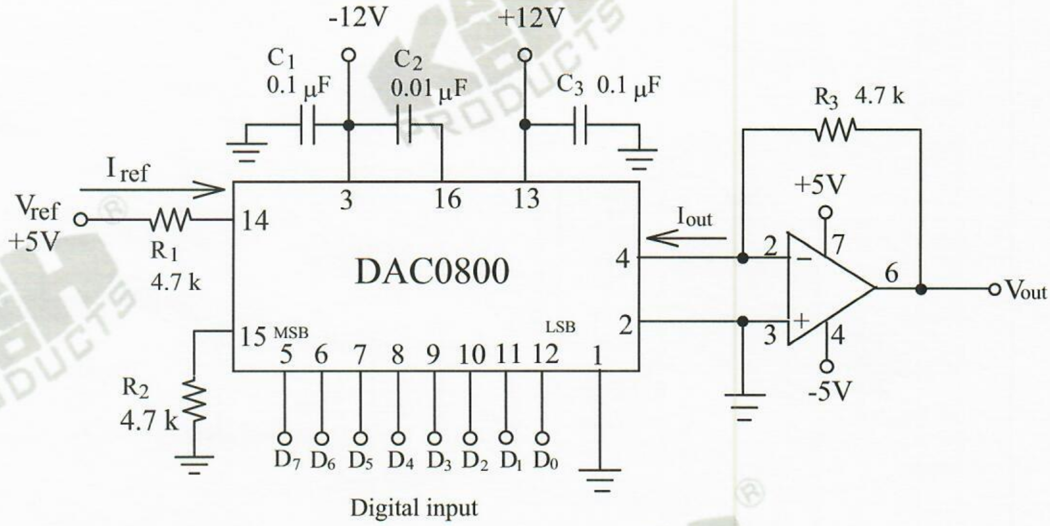

Fig.10-6 DAC0800 unipolar voltage output circuit

This I_{out} , the current flowing out of the converter, is then converted to an output voltage by the μA741. The voltage output V_{out} can be given by

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

The bipolar voltage output circuit of DAC0800 is shown in Fig. 10-7. The $\overline{I_{out}}$ pin is connected to the noninverting input of μA741 instead of to ground in Fig. 10-6. Thus the μA741 output voltage can be evaluated by

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

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

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

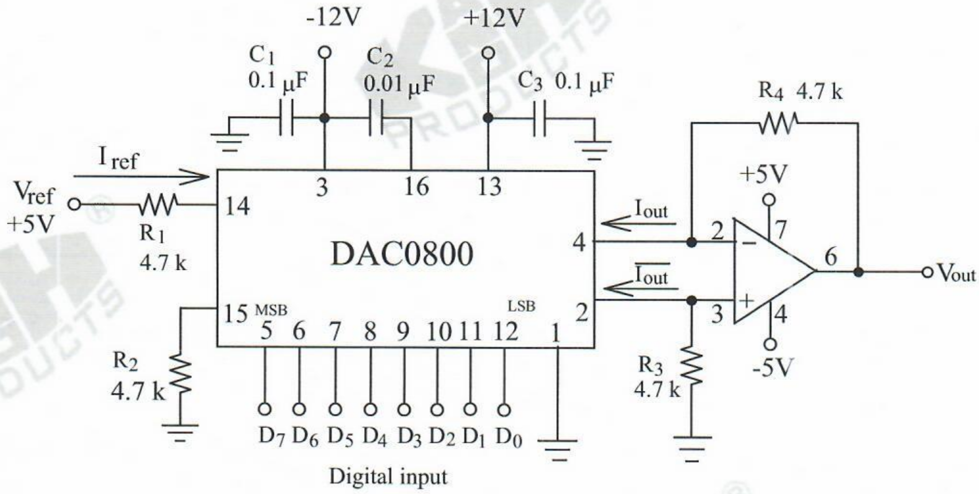

Fig.10-7 DAC0800 bipolar voltage output circuit

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

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

10.3 EQUIPMENT REQUIRED

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

10.4 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 μA741 input (pin 2).

□2. Calculate and record the step value in Table 10-1.

□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 10-1.

□5. Remove the connect plug from J1. Measure the I_{out} by connecting the DMM current meter between DAC0800 output and μA741 input. Record the result in Table 10-1.

□6. Remove the DMM and reinsert the connect plug in J1. Measure the output voltage V_{out} at μA741 output (O/P) using the DMM voltmeter and record the result in Table 10-1.

□7. Following the digital codes listed in Table 10-1, change the switches D_7 to D_0 and repeat steps 5 and 6 sequentially. Record the results in Table 10-1.

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 10-2.

□ 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 10-2.

□ 5. Using the DMM, measure the output voltage V_{out} and record the result in Table 10-2.

□ 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 10-2.

□ 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 10-2.

□ 8. Calculate the value of $I_{out}+\overline{I_{out}}$ and record the result in Table 10-2.

□ 9. Following the digital codes listed in Table 10-2, change the switches D_7 to D_0 and repeat steps 5 through 8 sequentially. Record the results in Table 10-2.

Table 10-1

Step Value =__________

Digital Input								Analog Output			
								V_{out}		I_{out}	
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	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 10-2

Step Value =____________

Digital Input								Analog Output				
								Calculated	Measured Value			
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	V_{out}	V_{out}	I_{out}	$\overline{I_{out}}$	$I_{out} + \overline{I_{out}}$
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

10.5 QUESTIONS

1. In Fig. 10-6, 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 10-2, comment on the relationship between I_{out} and $\overline{I_{out}}$.