

## EXPERIMENT 9 DIGITAL TO ANALOG CONVERTER

### 1. PURPOSE:

The first part includes the construction of digital-to-analogue converters using different techniques, namely the scaled resistors into summing junction, and the R-2R ladder. To expand our exposure to DAC, in the second part of this lab we will familiarize in the functioning of a commercially available DCA0832 chip

### 2. CONVERTING DIGITAL TO ANALOGUE:

It is often necessary to convert analog signal to an accurate digital number, and vice versa. For example, in applications where a microprocessor is controlling an experiment, the analogue signal from a sensor needs to be converted into digital form so it can be communicated to the microprocessor. After the processing takes place in the digital form, the output from the microcontroller needs to be converted back to the analogue form to communicate with the analogue world.

In this lab session we will consider the case of digital to analogue conversation (DAC). The converse process will be undertaken the following week. The DAC techniques presented here are not aimed at developing skills in converter designs. Rather, they aim at presenting the advantages and disadvantages of each method. In most cases, when embarked in an electronic project, one rather buys commercially available chips instead of building a converter from scratch. An understanding of DAC methods will guide you in selecting the more suitable one for the project at hand.

#### 2.1 Scaled resistors into summing junction

Implement the circuit shown in Fig. 1.

- a) Notice that the circuit has an input count of **16**; from 0 (with all the inputs OFF) to 15 (with all the inputs HIGH.)
- b) Verify that the circuit generates an output voltage from zero to (almost) **10 Volts**. The exact value is estimated below.

EXACT CALCULATION

- b1) Verify that the total maximum current through the gain resistor is given by,

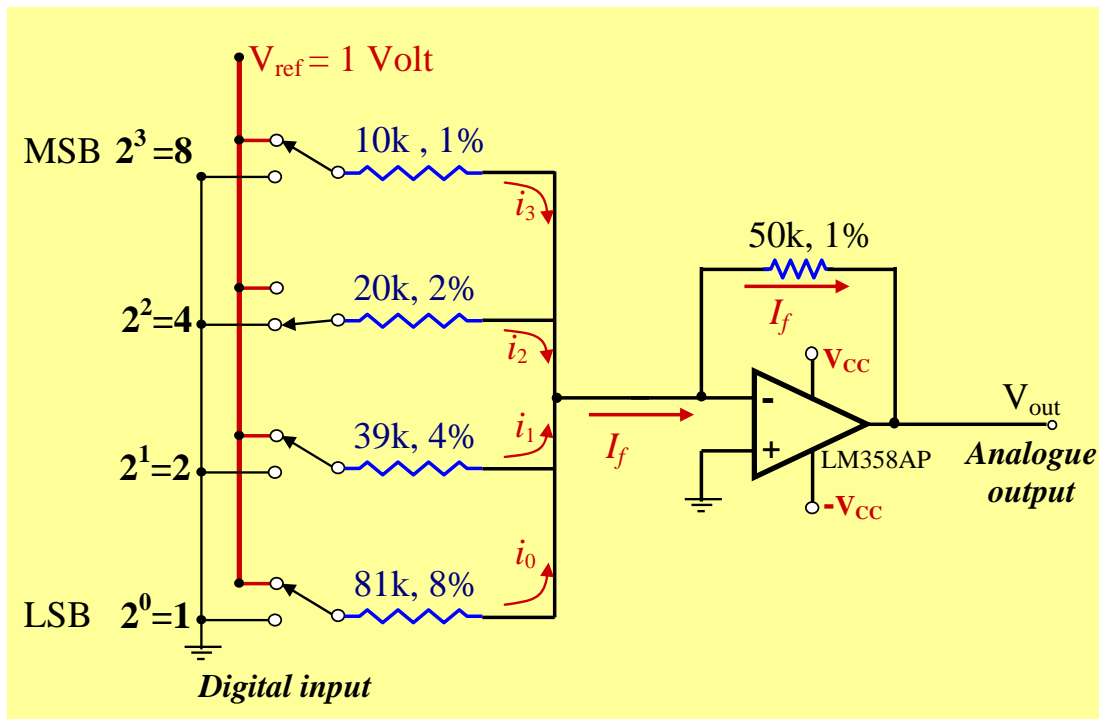
$$I_f = V_{ref} \frac{1}{10k\Omega} \left(1 + \frac{1}{2} + \frac{1}{2^2} + \frac{1}{2^3}\right)$$

- b2) Verify that the circuit generates an output voltage from zero to,

$$V_{out} = -V_{ref} \frac{50k\Omega}{10k\Omega} \frac{1 - (1/2)^4}{1 - (1/2)} = -V_{ref} 5 \frac{1 - (1/2)^4}{1 - (1/2)}$$

Equivalently,

$$V_{out} = -V_{ref} 5 \left[2 \frac{2^4 - 1}{2^4}\right] = -V_{ref} 10 \frac{15}{16}$$



**Fig. 1** Four-bit DAC

**c) GENERALIZATION (for  $n$ -bits DAC)**

In Fig. 1, consider adding input bits on the lower side (i.e. adding resistors whose values increase by a factor of 2) until  $n$  inputs are completed. Show that the following results are obtained:

The maximum input count is  $2^n - 1$  (all the  $n$  bits set to 1.)

The circuit generates an output voltage from zero to  $V_{out} = -V_{ref} 10 \left[ \frac{2^n - 1}{2^n} \right]$

**d) REQUIRED PRECISION of the RESISTORS**

**d1)** Show that for a given input (of resistance  $R$ ) in the DAC circuit, the desired contribution (only from that input) to the output voltage is  $V_{out} = -\frac{V_{ref}}{R} 50k\Omega$

**d2)** If the value of the resistor “ $R$ ” were to have an uncertainty  $\Delta R$  show that the corresponding uncertainty in the out voltage  $V_{out}$  is given by,

$$\frac{\Delta V_{out}}{V_{out}} = \frac{\Delta R}{R}$$

Thus, for a given required precision in the output voltage, the resistance at the MSB input require higher precision in the resistance value.

**e)** Make a table of the digital inputs in one column and the corresponding output voltage in another column, and verify if the obtained experimental values correspond with the predicted ones.

## 2.2 R-2R ladder

The scaled resistor technique becomes awkward for higher bits DAC. (A 12-bit converter would need a 2000:1 range of resistor values) with corresponding precision in the MSB input. The R-2R ladder, shown in Fig. 2 offers an elegant alternative.

- Only two resistor values are needed.
- Although the resistors must be precisely matched, the actual value of the resistors is not critical.

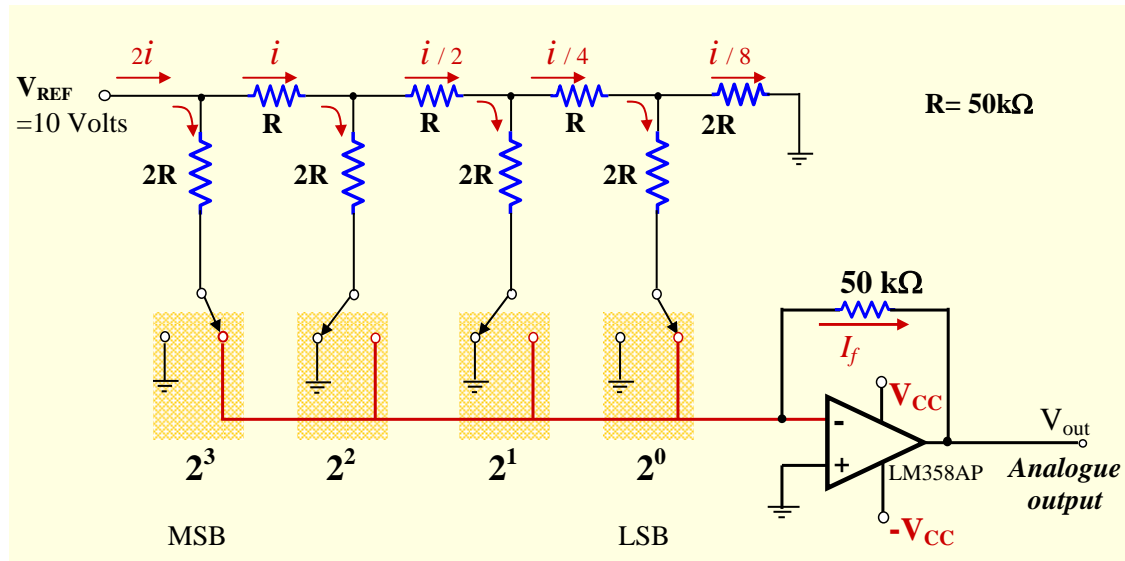


Fig. 2 Four-bit DAC

- Verify that the distribution of current along the network of resistance.
- Calculate and verify experimentally that the contribution to the output voltage from the MSB is -5V.  
Verify that the contribution to the output voltage from the other inputs decrease by a factor of 2, from bit to the next.
- Calculate and verify experimentally that the maximum magnitude of the output voltage is  $V_{ref} \frac{15}{16}$ .

## 2.3 Using a commercial DAC

We will use the DCA0832 chip, familiarizing with the different inputs and outputs of this chip.

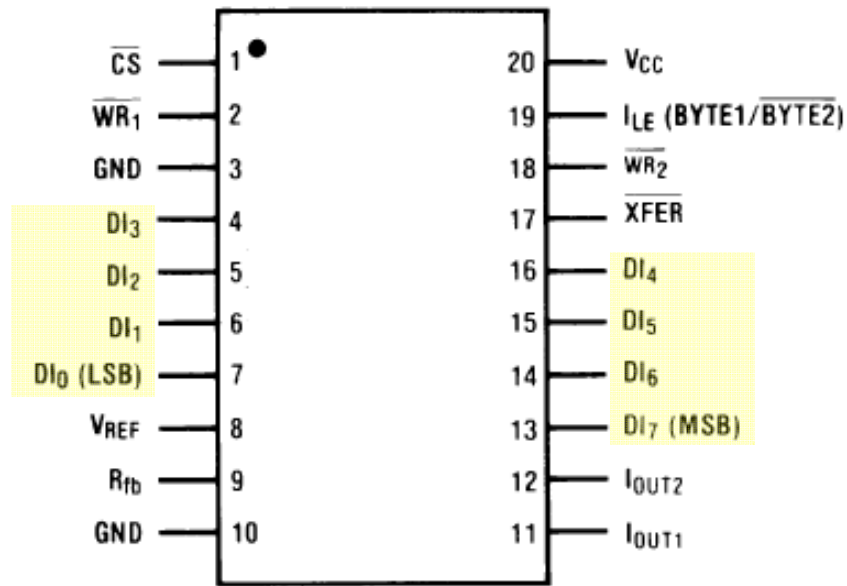
The  $V_{CC}$  pin should be connected to 15 V DC for optimal operation but can be as low as 5 V DC.

The  $V_{REF}$  input pin can vary from -10 V DC to +10 V DC.

The  $CS$ ,  $WR_1$ ,  $XFER$ ,  $WR_2$  are “active low” which means they are active with low voltage.

When  $WR_1$  is active then everything signal placed in the inputs will be loaded into the input register. The  $XFER$  will enable the transfer from the input register to the DAC register.

To allow for the transfer to both register  $I_{LE}$  should be high.



The output of **I<sub>out1</sub>** will be

$$I_{out1} = \frac{V_{ref}}{15k\Omega} \times \frac{DigitalNumber}{256}$$

You should enter any number between 0 and 255 and it will be useful to have LED connected to the inputs and outputs.