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Experiment No. 5
Digital to Analog Conversion

1. Introduction

1.1 Objective:

- Study of 4 Bit R-2R Ladder.
- Obtain analog voltage from digital signal.

1.2 Components:

1. ST2611 Digital Circuit Development Platform trainer with power supply cord.
2. DB16 – Digital to Analog Converter.
3. Multimeter.
4. Set of wires.

1.3 Theory:

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 analog 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 analog form to communicate with the analog world.

In this lab session we will consider the case of digital to analog conversion (DAC). A digital to analog converter (DAC) converts a digital signal to an analog voltage or current output. Many types of DACs are available and usually switches, resistors, and op-amps are used to implement the conversion.

R-2R Ladder is another type of DAC based on the opamp summing amplifier similarly as seen in Figure (1). It uses only two values of resistors which makes the fabrication of the circuit easier and more accurate. R-2R ladder can scalable to any number of bits desired and its output impedance will remain R, regardless the number of bits. In this experiment we will assume that feedback resistor RF is equal to “R” .Each bit corresponds to a switch:

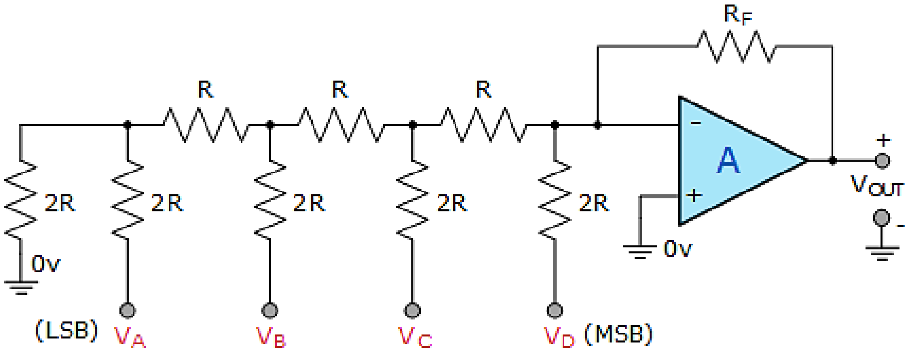

Figure 1: 4-Bit R-2R Ladder (DAC)

The digital logic circuit used to drive the D/A converter can be generated by combinational or sequential logic circuits, data registers, counters or simply switches. The interfacing of a R-2R D/A converter of "n"-bits will depend upon its application.

Generalised R-2R DAC Equation:

$$Vout = -\frac{1V_A + 2V_B + 4V_C + 8V_D + 16V_E + 32V_F + \cdots etc}{2^n}$$

Where: "n" represents the number of digital inputs within the R-2R resistive ladder network of the DAC producing a resolution of: $V_{LSB} = V_{IN}/2^n$.

Clearly then input bit V_A when HIGH will cause the smallest change in the output voltage, while input bit V_D when HIGH will cause the greatest change in the output voltage. The expected output voltage is therefore calculated by summing the effect of all the individual input bits which are connected HIGH.

Ideally, the ladder network should produce a linear relationship between the input voltages and the analogue output as each input will have a step increase equal to the LSB, we can create a table of expected output voltage values for all 16 combinations of the 4 inputs with +5V representing a logic "1" condition as shown.

Decimal Numerals	Digital Input				Analog Output
Decimal	**D3**	**D2**	**D1**	**D0**	**Vout**
0	0	0	0	0	0
1	0	0	0	1	-0.3125
2	0	0	1	0	-0.6250
3	0	0	1	1	-0.9375
4	0	1	0	0	-1.2500
5	0	1	0	1	-1.5625
6	0	1	1	0	-1.8750
7	0	1	1	1	-2.1875
8	1	0	0	0	-2.5000
9	1	0	0	1	-2.8125
10	1	0	1	0	-3.1250
11	1	0	1	1	-3.4375
12	1	1	0	0	-3.7500
13	1	1	0	1	-4.0625
14	1	1	1	0	-4.3750
15	1	1	1	1	-4.6875

Table 1: Digital to Analog Conversion

Notice that the full-scale analogue output voltage for a binary code of 1111 never reaches the same value as the digital input voltage (+5V) but is less by the equivalent of one LSB bit, (312.5mV in this example). However, the higher the number of digital input bits (resolution) the nearer the analogue output voltage reaches full-scale when all the input bits are HIGH. Likewise when all the input bits are LOW, the resulting lower resolution of LSB makes V_{OUT} closer to zero volts.

Example: A 4-bit R-2R digital-to-analogue converter is constructed to control the speed of a small DC motor using the output from a digital logic circuit. If the logic circuit uses 5 volt TTL devices, calculate the analogue output voltage from the DAC when the input code is hexadecimal number "B". Also determine the resolution of the DAC.

Solution:

1) The hexadecimal letter "B" is equal to the number eleven in decimal. The decimal number eleven is equal to the binary code "1011" in binary. That is: $B_{16} = 1011_2$. Thus for our 4-bit binary number of 1011_2, input bit D = 1, bit C = 0, bit B = 1 and bit A = 1.

   The digital logic circuit uses 5 volt TTL devices, so the input voltage to the R-2R network will be 5 volts. Using our equation from above, the ouput voltage for a binary code of 1011_2 is calculated as:

$$Vout = -\frac{1V_A + 2V_B + 4V_C + 8V_D}{2^n}$$

$$Vout = -\frac{1*5 + 2*5 + 4*0 + 8*5}{2^4}$$

$$Vout = -3.4375\ volts$$

   Therefore the analogue output voltage used to control the DC motor when the input code is 1011_2 is calculated as: -3.4375 volts. Note that the output voltage is negative due to the inverting input of the operational amplifier.

2) The resolution of the converter will be equal to the value of the least significant bit (LSB) which is given as:

$$Resolution = V_{(LSB)} = \frac{V_{IN}}{2^n}$$

$$Resolution = V_{(LSB)} = \frac{5}{16} = 0.3125$$

Then the smallest step change of the analogue output voltage, V_{OUT} for a 1-bit LSB change of the digital input of this 4-bit R-2R digital-to-analogue converter example is: 0.3125 volts. That is the output voltage changes in steps or increments of 0.3125 volts and not as a straight linear value.

2. Experiments:

2.1 Exercise 1 Setup +12V and -12V Voltage Supply:

In this exercise, you need to set up the +12V and -12 V from the variable voltage supply using the multimeter.

1. Connect a wire from the V pin of the multimeter to the +3.. 15V on the left side of the trainer.
2. Connect the COM pin of the multimeter to GND pin on the trainer.
3. Turn the multimeter and the trainer on and start measuring the supplied voltage.
4. Turn the knob of +V clockwise or counterclockwise until you get +12V then stop moving the knob.
5. Take the wire connected to +3.. 15V and place it to -3.. 15V pin and repeat step no. 4 but this time until you get -12V.
6. Take off all the wires from the trainer and turn it off.

2.2 Exercise 2 Convert Digital to Analog Signal:

1. Place the DB16 panel as shown in Figure (2) on the trainer.
2. To provide power to the panel, connect a wire from +3.. 15V pin on the left side of the trainer board to +12V pin on the left side of DB16.
3. Connect a wire from -3.. 15V pin on the left side of the trainer board to -12V pin on the left side of DB16.
4. Connect GND pin from the trainer on the left side to ground symbol pin on the DB16.
5. Connect the input switches which are pins no. D0, D1, D2 and D3 on the bottom of the trainer to D0, D1, D2, and D3 pins on the bottom of the panel respectively.
6. Connect a wire from the V pin of the multimeter to the V0 on the right side of DB16.
7. Connect the COM pin of the multimeter to ground symbol bellow V0 on the DB16.
8. Make sure all your connections are right then turn on the power supply.
9. Turn D1 and D2 switches to position 1 while keep D0 and D3 switches at position 0 then observe the output on the multimeter and write it in the Table (1).
10. Observe the output for different input combination as shown in the table of digital to analog conversion on Table (1) and write the results you get.

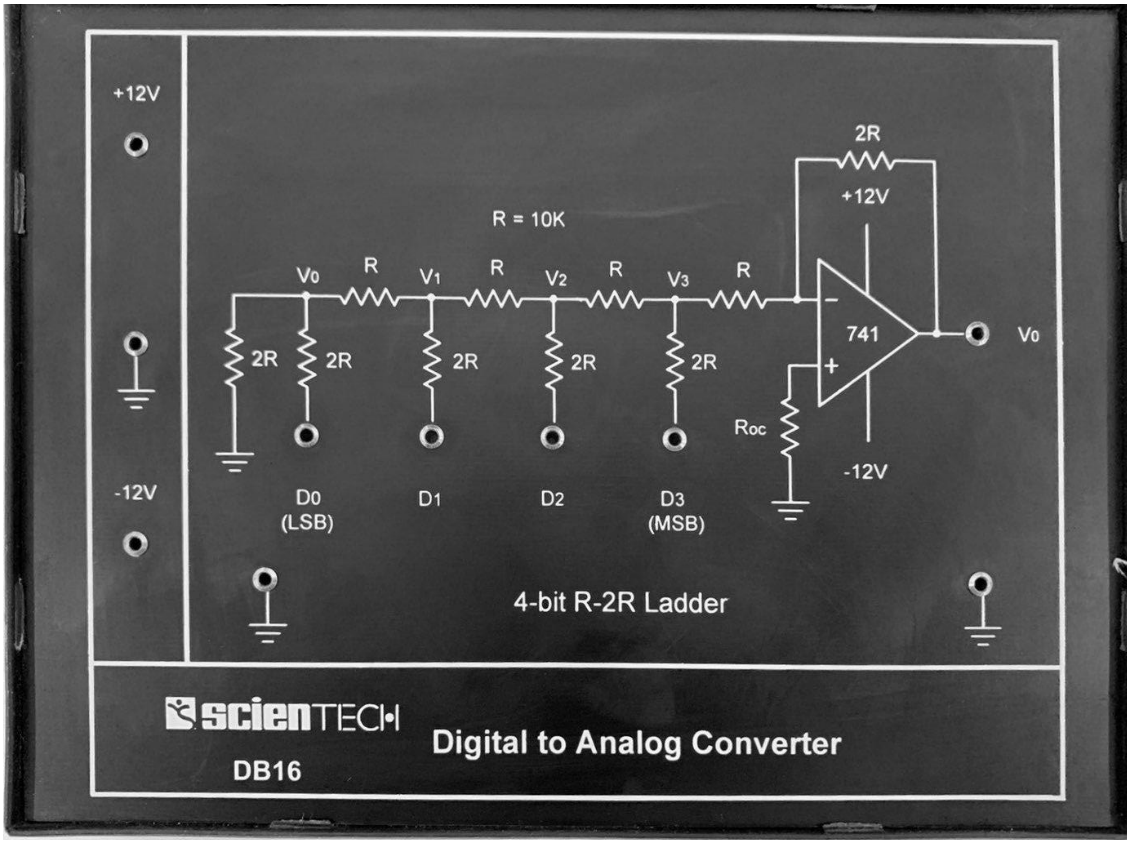

Figure 2: DB16 Digital to Analog Converter Panel (4-Bit R-2R Ladder)

3. Discussion:

1. What is the purpose of using digital to analog conversion?
2. What is the sign of the output voltage of the R-2R ladder? Why?
3. Solve the analog conversion for 8-bit binary numbers 10101111_2 ?
4. Compare the results you obtained by hand with the results from the lab and discuss it in the report. Are they similar or not? Why?
5. How you can operate a DC motor work with 3.7 volt ? Keep in mind that the motor is controlled by a microprocessor that works by Hexadecimal number system.