Title: Design of a Digital to Analog Converter (Part I)

Introduction:

This lab describes the design of a Digital to Analog Converter (DAC). Two types of design are shown in this lab, binary-weighted DAC and R/2R ladder DAC design. And at the end of the experiment, we compared both designs to conclude which design is efficient.

Theory and Methodology:

One common requirement in electronics is to convert signals back and forth between analog and digital forms. Most such conversions are ultimately based on a *digital-to-analog converter* circuit. Therefore, it is worth exploring just how we can convert a digital number that represents a voltage value into an actual analog voltage.

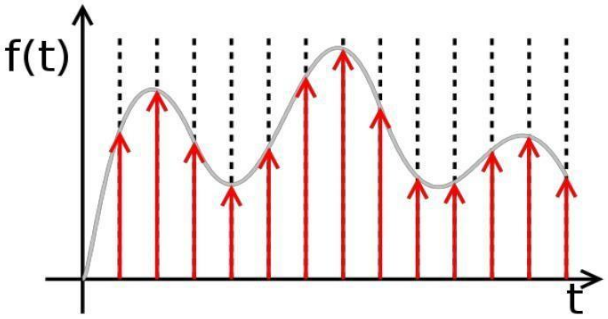
Digital-to-Analog Converters

In electronics, a digital-to-analog converter (DAC, D/A, D2A or D-to-A) is a function that converts digital data (usually binary) into an analog signal (current, voltage, or electric charge). An analog-to-digital converter (ADC) performs the reverse function. Unlike analog signals, Digital data can be transmitted, manipulated, and stored without degradation, albeit with more complex equipment. But a DAC is needed to convert the digital signal to analog, for example to drive an earphone or loudspeaker amplifier and produce sound (analog air pressure waves).

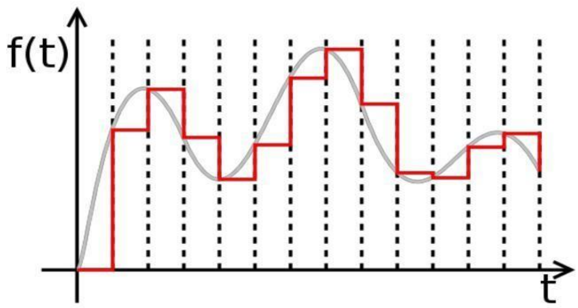
DACs and their inverse, ADCs, are part of an enabling technology that has contributed greatly to the 'digital revolution'. To illustrate this, consider a typical long-distance telephone call. The caller’s voice is converted into an analog electrical signal by a microphone. The analog signal is then converted to a digital stream by an ADC. That digital stream is then divided into packets where it will be mixed with other digital data, not necessarily audio. The digital packets are then sent to the destination, but each packet may take a completely different route and may not even arrive at the destination in the correct time order. The digital voice data is then extracted from the packets and assembled into a digital data stream. A DAC converts it into an analog electrical signal which drives an audio amplifier which in turn drives a loudspeaker which finally produces sound. Of course, this is a simplified and stylized description, but it does illustrate one vital role of ADCs and DACs.

There are several DAC architectures; the suitability of a DAC for a particular application is determined by six main parameters: physical size, power consumption, resolution, speed, accuracy, cost. Due to the complexity and the need for precisely matched components, all but the most specialist DACs are implemented as integrated circuits (ICs). Digital-to-analog conversion can degrade a signal, so a DAC should be specified that that has insignificant errors in terms of the application.

DACs are commonly used in music players to convert digital data streams into analogue audio signals. They are also used in televisions and mobile phones to convert digital video data into analog video signals which connect to the screen drivers to display monochrome or color images. These two applications use DACs at opposite ends of the speed/resolution trade-off. The audio DAC is a low-speed high resolution type while the video DAC is a high-speed low to medium resolution type. Discrete DACs would typically be extremely high-speed low-resolution power-hungry types, as used in military radar systems. Very high-speed test equipment, especially sampling oscilloscopes, may also use discrete DACS.



Ideally sampled signal



Piecewise constant output of an idealized DAC lacking a reconstruction filter. In a practical DAC, a filter or the finite bandwidth of the device smoothes out the step response into a continuous curve.

A digital-to-analog converter, or DAC for short, converts a digitally coded number to a voltage proportional to the number. For example, if a number N is supplied to a DAC, the output voltage will be proportional to N: $V_{out} = N \times B$ The constant of proportionality, B, is normally determined from the ratio of the reference voltage, V_{ref}, and the maximum value that N can have, N_{max}, $B = V_{ref} / N_{max}$ so that $V_{out} = V_{ref}\, N / N_{max}$.

A common way to make a DAC is with an Op Amp circuit. Recall the circuit for the summing amplifier.

Binary Weighted Digital-to-Analog Converter:

The following circuit is a basic digital-to-analog (D to A) converter. It assumes a 4-bit binary number in Binary-Coded Decimal (BCD) format, using +5 volts as a logic 1 and 0 volts as a logic 0. It will convert the applied BCD number to a matching (inverted) output voltage. The digits 1, 2, 4, and 8 refer to the relative weights assigned to each input. Thus, 1 is the Least Significant Bit (LSB) of the input binary number, and 8 is the Most Significant Bit (MSB).

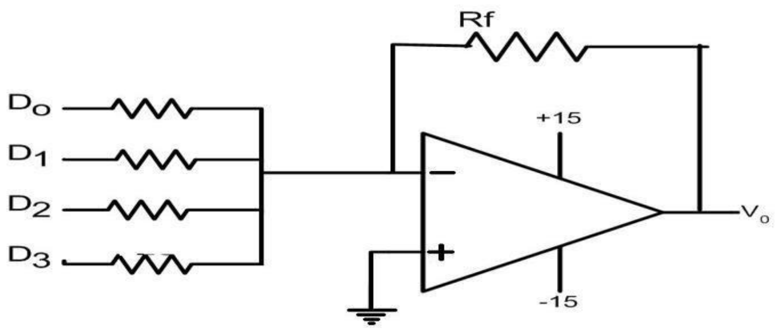


Fig1: Binary Weighted Digital to Analog converter.

If the input voltages are accurately 0 and +5 volts, then the "1" input will cause an output voltage of -5 × (4k/20k) = -5 × (1/5) = -1 volt whenever it is a logic 1. Similarly, the "2," "4," and "8" inputs will control output voltages of -2, -4, and -8 volts, respectively. As a result, the output voltage will take on one of 10 specific voltages, in accordance with the input BCD code.

Unfortunately, there are several practical problems with this circuit. First, most digital logic gates do not accurately produce 0 and +5 volts at their outputs. Therefore, the resulting analog voltages will be close, but not really accurate. In addition, the different input resistors will load the digital circuit outputs differently, which will almost certainly result in different voltages being applied to the summer inputs.

R/2R Ladder Digital-to-Analog Converter:

This improved circuit overcomes the problem of using many resistors. Instead, it uses only two valued resistors.

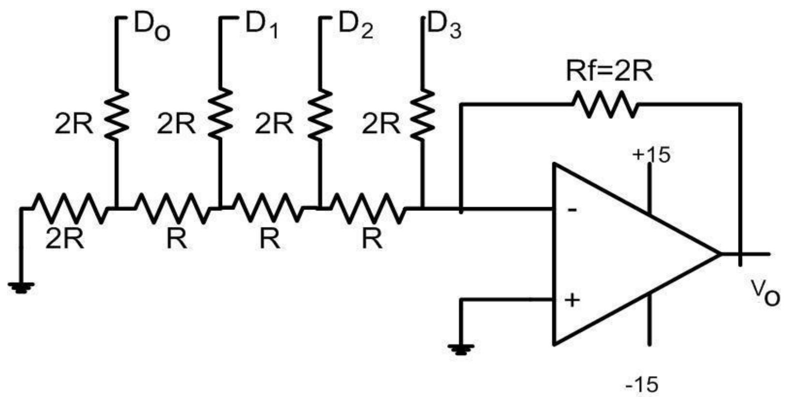


Fig 2: R/2R Ladder DAC

The circuit above performs a D to A conversion a little differently. Typically, the inputs are driven by CMOS gates, which have low but equal resistance for both logic 0 and logic 1. Also, if we use the same logic levels, CMOS gates really do provide +5 and 0 volts for their logic levels.

The input circuit is a remarkable design, known as an R-2R ladder network. It has several advantages over the basic summer circuit we saw first:

1. Only two resistance values are used anywhere in the entire circuit. This means that only two values of precision resistance are needed, in a resistance ratio of 2:1. This requirement is easy to meet, and not especially expensive.

2. The input resistance seen by each digital input is the same as for every other input. The actual impedance seen by each digital source gate is 3R. With a CMOS gate resistance of 200 ohms, we can use the very standard values of 10k and 20k for our resistors.

3. The circuit is indefinitely extensible for binary numbers. Thus, if we use binary inputs instead of BCD, we can simply double the length of the ladder network for an 8-bit number (0 to 255) or double it again for a 16-bit number (0 to 65535). We only need to add two resistors for each additional binary input.

4. The circuit lends itself to a non-inverting circuit configuration. Therefore, we need not be concerned about intermediate inverters along the way. However, an inverting version can easily be configured if that is appropriate.

Pre-Lab Homework:

Why DACs has been an integral part of electronics for decades?

Ans: In modern life, electronic equipment is frequently used in different fields such as communication, transportation, entertainment, etc. Analog to Digital Converter (ADC) and Digital to Analog Converter (DAC) are very important components in electronic equipment. Since most real-world signals are analog, these two converting interfaces are necessary to allow digital electronic equipment to process the analog signals. ADC converts the analog signal collected by audio input equipment, such as a microphone, into a digital signal that can be processed by a computer. The computer may add sound effects such as echo and adjust the tempo and pitch of the music. DAC converts the processed digital signal back into the analog signal that is used by audio output equipment such as a speaker. That’s why DAC is so important.

Where are DAC and ADC vastly used?

Ans: In modern life, electronic equipment is frequently used in different fields such as communication, transportation, entertainment, etc. Analog to Digital Converter (ADC) and Digital to Analog Converter (DAC) are very important components in electronic equipment.

Apparatus:

1) IC741 OPAMP 1[pcs]
2) Resistors as required. 14[pcs]
3) Oscilloscope.

Precautions:

Never turn on the DC source before the circuit is placed correctly and checked carefully.
Check for short circuits in the circuit.

Experimental Procedure:

1) First setup the Binary Weighted Digital to Analog converter as shown in Fig1 on the trainer board.
2) Put the following sequence 1010 to D0, D1, D2 and D3 respectively. See the output on the oscilloscope.
3) Again, setup the R/2R ladder on the trainer board.
4) Repeat step 2 for R/2R DAC.

Simulation and Results:

1. Draw a plot on graph paper showing relationship between digital input and analog output of digital-to-analog-converter.

Experimental Simulation:

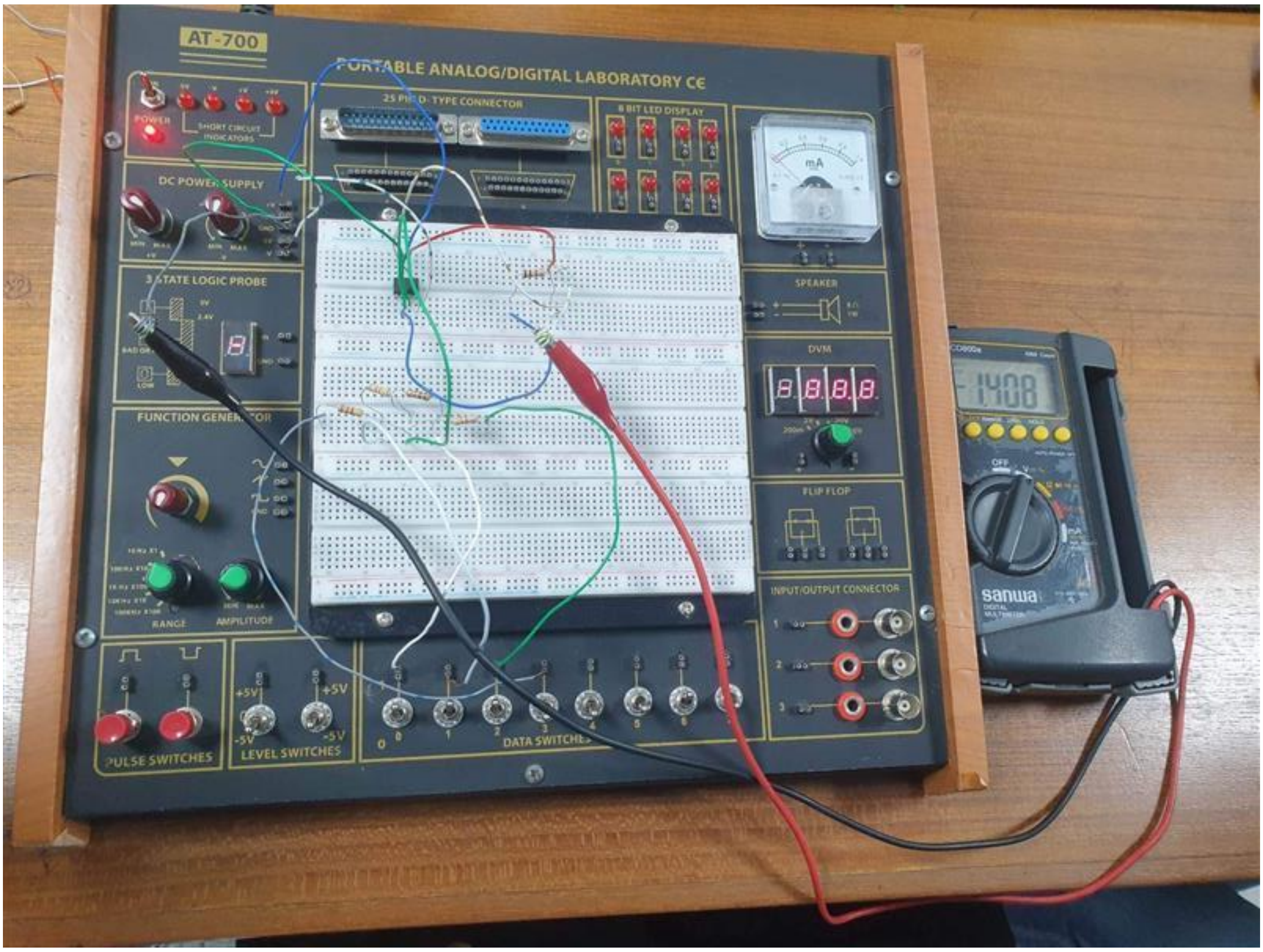


Fig1: Binary Weighted Digital to Analog converter

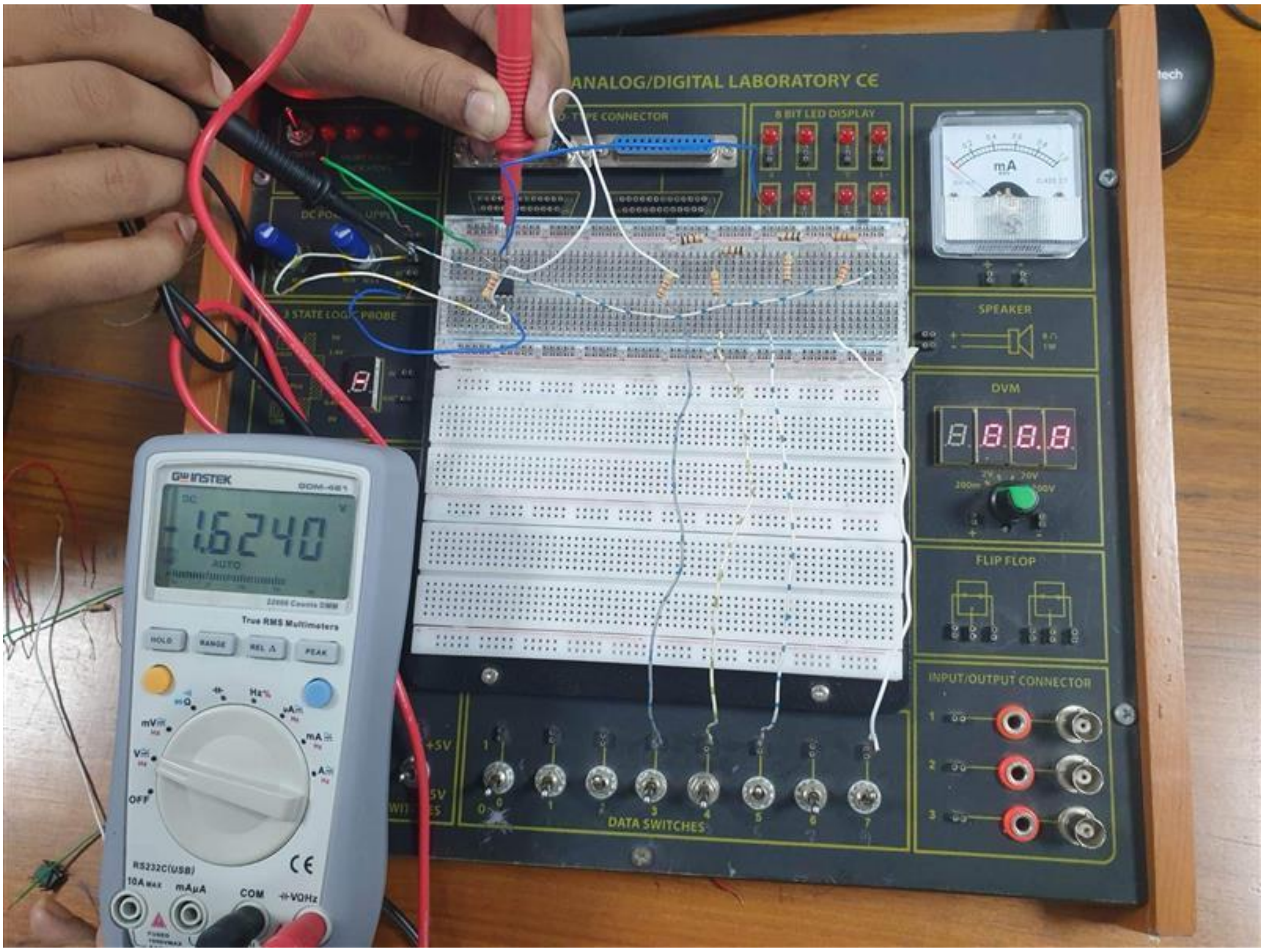


Fig 2: R/2R Ladder DAC

Data Table:

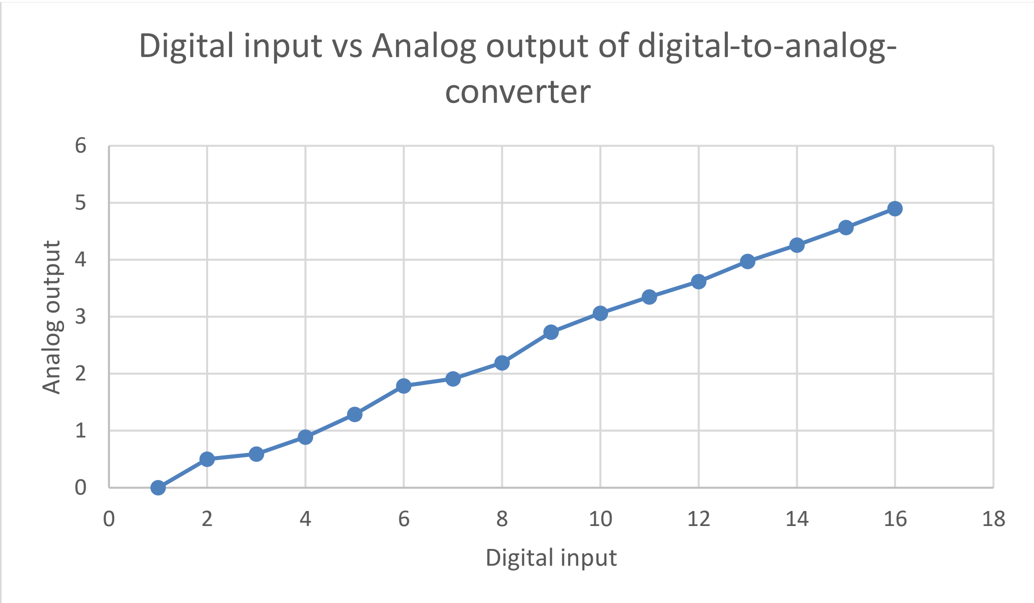
Table 01:

Input	Output(V)
0000	-0.03
0001	-0.5
0010	-1.00
0011	-1.46
0100	-1.86
0101	-2.2
0110	-2.61
0111	-3.04
1000	-2.89
1001	-3.4
1010	-3.85
1011	-4.4
1100	-4.8
1101	-5.4
1110	-5.82
1111	-6.25

Table 02:

Input				Output
A	B	C	D	
0	0	0	0	-0.0123V
0	0	0	1	-0.56V
0	0	1	0	-1.06V
0	0	1	1	-1.73V
0	1	0	0	-2.117V
0	1	0	1	-2.72V
0	1	1	0	-3.26V
0	1	1	1	-3.95V
1	0	0	0	-3.83V
1	0	0	1	-4.43V
1	0	1	0	-4.93V
1	0	1	1	-5.55V
1	1	0	0	-5.96V
1	1	0	1	-6.49V
1	1	1	0	-7.11V
1	1	1	1	-7.80V

Graph:



2. Use PSPICE for software simulation.
   Simulation:

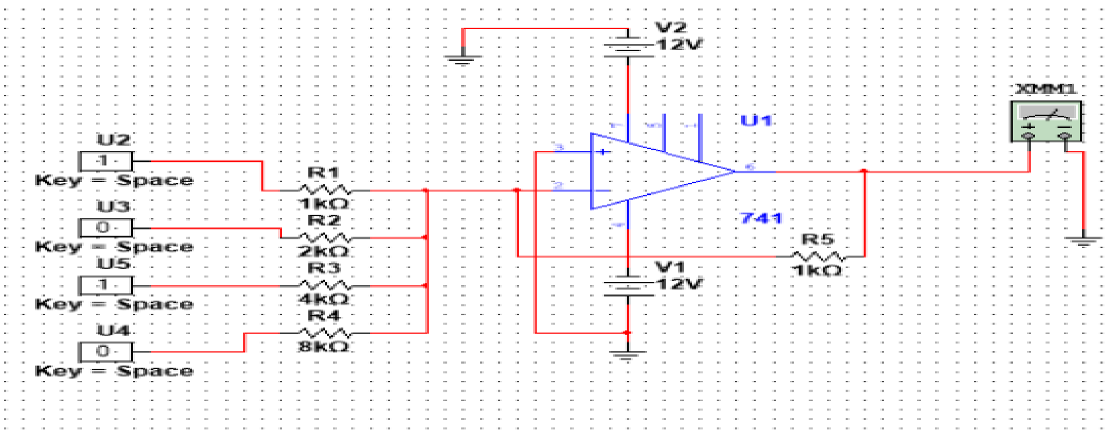


Fig 5: Simulation of Binary Weighted Digital-to-Analog Converter

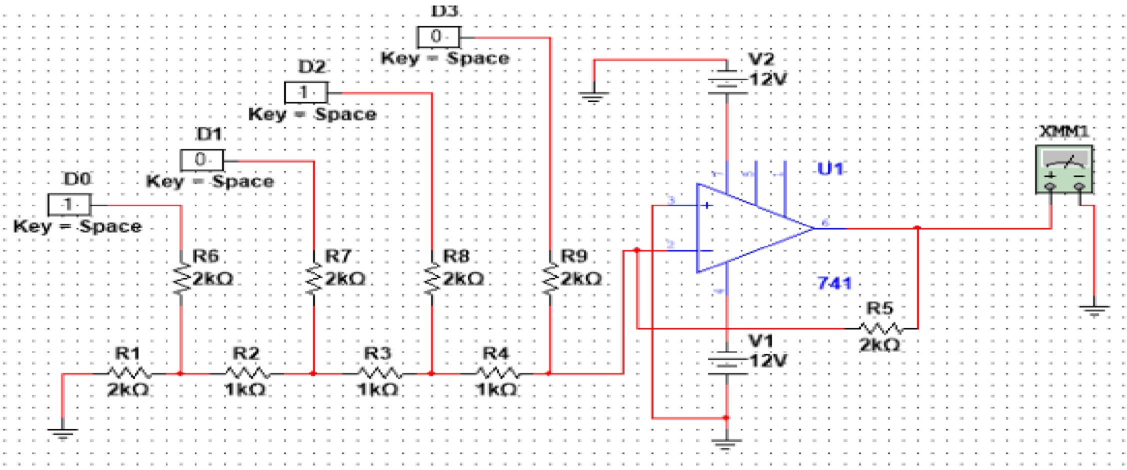


Fig 5: Simulation of Binary R/2R Ladder Digital-to-Analog Converter

Questions for report writing:

1. Why R/2R Ladder Digital-to-Analog Converter is preferable than Binary weighted Digital-to-Analog Converter.

Ans:

The R-2R Ladder DAC overcomes the disadvantages of a binary weighted resistor DAC. As the name suggests, R-2R Ladder DAC produces an analog output, which is almost equal to the digital (binary) input by using a R-2R ladder network in the inverting adder circuit. In the case of binary-weighted DAC a wide range of resistances is required which makes it more expensive as compared to R 2R. R-2R DAC is more accurate when compared to Binary weighted DAC. It is Easier to build accurately as only two precision metal film resistors are required. A few bits can be expanded by adding more sections of the same R/2R values. In inverted R/2R ladder DAC, node voltages remain constant with changing input binary words. This avoids any slowdown effects by stray capacitances.

Discussion:

As seen in the results and simulation section, the binary weighted digital to analog converter has been implemented properly in the simulation tool as the simulation is giving the proper output. It can be analyzed that more the number increase the voltage follows a pattern. As this is a 4-bit DAC this only has 16 outputs. When the bits increase the circuit will eventually become more complex but this one will help to build more complex binary weighted DAC.

Conclusion:

The binary weighted DAC has been implemented with the simulation approach which is completely different than the real-life hardware approach. After the implemented the output was gotten which was desired which proves the experiment is successful. This experiment will help to get a proper grip on the digital to analog converter

Reference:

[1] Thomas L. Floyd, Digital Fundamentals, 9th Edition, 2006, Prentice Hall.