Digital to Analog Converter (DAC) and Analog to Digital Converter(ADC) Circuits

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In modern life, electronic equipment is frequently used in different fields such as communication, transportation, entertainment, etc. Analog to Digital Converters (ADC) and Digital to Analog Converters (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 equipments to process the analog signals. In this experiment, we are constructing the simplest conversion circuits, i.e., a 3-bit DAC and a 2-bit ADC to verify the conversion procedure. These circuits can be used as the basis for the construction of converters with higher bits.

I. OBJECTIVES

- To construct and study DAC and ADC using various linear and digital ICs.

II. THEORY

A. Digital-to-Analog Converters (DAC)

DAC converts the digital signal into the analog signal. The addition of digital inputs (0 or 1, where 1 corresponds to 5 volts) results in analog output, which can be added with different weights depending on their position in the binary number.
However, this type of circuit has the disadvantage of requiring a large number of accurate resistors for a large number of bits. For example, an 8-bit converter requires eight resistors with values ranging from R to 128R. This is eliminated by the R/2R ladder DAC circuit (FIG. 1).

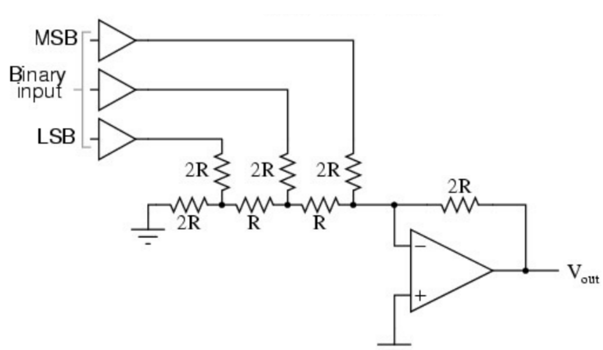

FIG. 1. R/2R ladder DAC circuit for a 3-bit converter using 741 op-amp

The output voltage of the DAC circuit is given by:

$$V_{out} = -\frac{R_F}{R}\left(\frac{d_1}{2^1} + \frac{d_2}{2^2} + \frac{d_3}{2^3}\right) \tag{1}$$

where d_1 is M.S.B and d_3 is L.S.B.
In the above circuit, feedback resistance $R_F = 2$R.
The output impedance of the R-2R network is always R, regardless of the number of bits in the network. Another advantage of the circuit is that it simplifies the design of circuits that use DAC, such as filtering and amplification.

1. *Performance of DAC*

The performance of DAC is characterized by:

- **Resolution:** The Resolution of a Digital to Analog Converter is defined as:

$$Resolution = \frac{1}{2^N - 1} \tag{2}$$

  where N is the total number of bits. This value is usually expressed in percentages.

- **Accuracy:** It is a comparison of the actual output of the converter with the expected output.

- **Settling time:** It is the amount of time it takes the converter to settle within $\pm\frac{1}{2}$ of the least significant bit of its final value after the converter has been given input.

- **Power supply sensitivity:** is defined as:

$$\frac{\Delta V_o}{\Delta V_s} \tag{3}$$

  where V_o is the output voltage, V_s is the source voltage and it is usually expressed in percentages. An ideal converter would have 0% power supply sensitivity.

- **Monotonicity:** In electronics, a monotonic DAC is one in which the analog output follows the direction of the digital input, no matter how the digital input varies.

B. Analog-to-Digital Converters (ADC)

This circuit is for the conversion of analog input (any physical quantity such as temperature) to digital output in binary form (which can be read by a computer) and further, it can be converted to binary decimal format. The circuit diagram for the conversion is given in FIG 2.

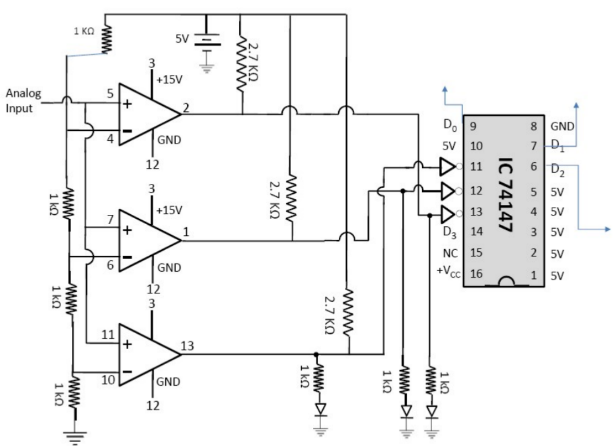

FIG. 2. A 2-bit ADC circuit using LM339 comparator and 74147 priority encoder

For the 74147 IC, the input is active low and the output is active low.

III. EXPERIMENTAL SETUP

A. DAC circuit

- **IC 741 op-amp:** Linear IC used in DAC circuits.

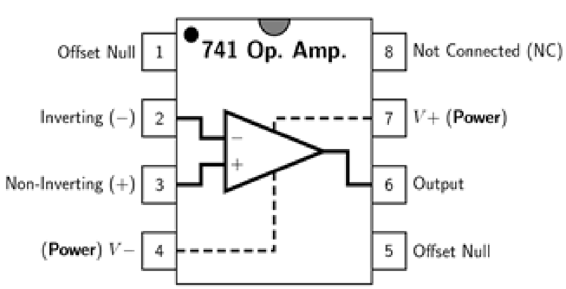

FIG. 3. Pin diagram of IC 741 op-amp

- **Power supply**
- **Resistors, Connecting wires, breadboard:** to connect the circuits.

The circuit diagram for the 3-bit Digital-to-Analog converter is shown in FIG.1.

B. ADC circuit

- **LM339 comparator chip:**

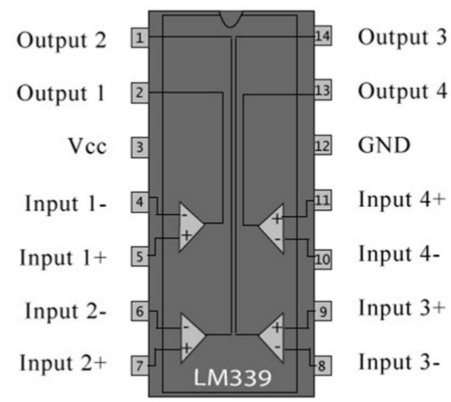

FIG. 4. Pin diagram of LM339 comparator chip

It is a quad-comparator integrated circuit. It has an open collector, therefore requires pull-up resistors as shown in FIG 2 at the output of the comparator.

- **IC 74147 priority encoder:**

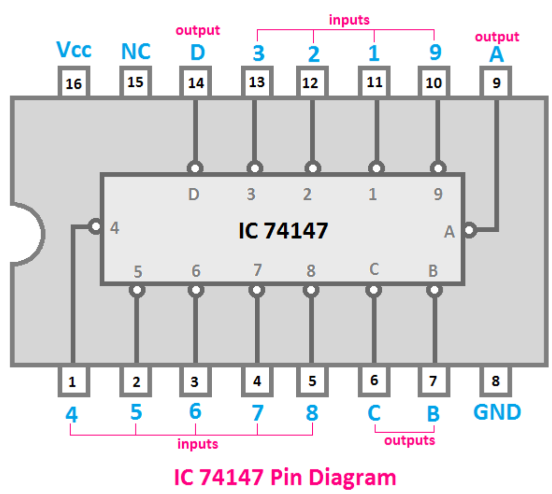

FIG. 5. Pin diagram of IC74147 priority encoder

The outputs D_2, D_1 and D_0 are taken from pin numbers 6,7 and 9 respectively and the inputs are taken from the NOT gate outputs in pins 11, 12 and 13.

- **LEDs:** to visualize the digital output for a given analog input. Generally, LEDs are connected along with $1k\Omega$ resistors to increase their life span.

- **Resistors, Connecting wires, Breadboard:** to connect the circuit as shown in FIG.2.

IV. OBSERVATIONS AND DATA

Table 1: Data for 3-bit DAC circuit

Input			Vdc (Volt)	Theoretical Value(Volt)
MSB	Binary	LSB		
0	0	0	0.001	0
0	0	1	-1.305	-1.2625
0	1	0	-2.614	-2.525
0	1	1	-3.92	-3.7875
1	0	0	-5.2	-5.05
1	0	1	-6.51	-6.3125
1	1	0	-7.82	-7.575
1	1	1	-9.12	-8.8375

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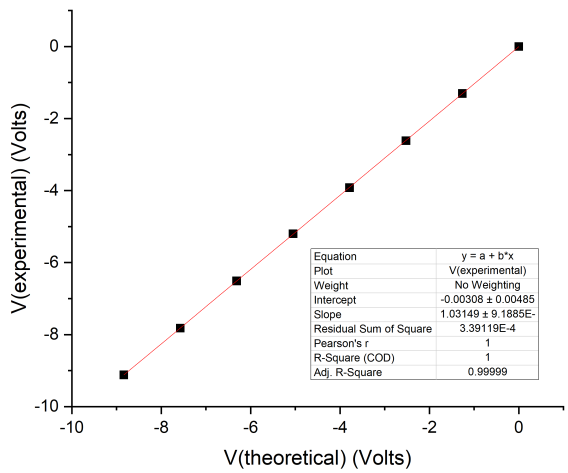

FIG. 6. Plot of $V_{experimental}$ vs $V_{theoretical}$ for DAC circuit

Table 2: Data for 2-bit ADC circuit

Analog Input	D0	D1	D2
0	1	1	1
1.5	1	0	1
2.9	0	1	1
4.3	0	0	1

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V. CONCLUSIONS

- The analog output in the DAC circuit well suffices well with the theoretically calculated value using eqn. (1).
- The slope of the plot of $V_{experimental}$ vs $V_{theoretical}$ for DAC circuit comes out to be (1.0315 ± 0.0009) which is expected to be 1, but it got some errors mentioned later in the report.
- The digital output in the ADC circuit comes out to be exactly opposite of the corresponding input, due to the use of NOT gates as IC74147 is an active low pass priority encoder. So, we can conclude that the digital output also suffices the analog input. The digital output D_2 is always constant.
- Thus, we have constructed a 3-bit DAC circuit and a 2-bit ADC circuit efficiently.
- These circuits can be used as the basic unit for advanced converter circuits with a large number of bits used in modern-day computers.

VI. SOURCES OF ERRORS AND PRECAUTIONS

- Electrical noises in the input in the case of ADC circuit and in the output in the case of DAC circuits.
- Always follow the pin diagram of the corresponding ICs, otherwise, the IC will blow up.
- LEDs should always be connected along with resistors and should be grounded.
- Loose connections should be avoided in the circuit.

VII. REFERENCES

- NISER Lab Manual
- `http://denethor.wlu.ca/pc300/daad_lec2/daad_lec.htm`
- `http://www.cmm.gov.mo/eng/exhibition/secondfloor/MoreInfo/ADConverter.html`