Study of R2R 4-Bit and 8-Bit DAC Circuit using Multisim Technology

Raghavendra. R[1], S. A Hariprasad[2], M. Uttara Kumari[3]

[1, 2, 3] R. V college of Engineering, Bangalore, Karnataka India

Abstract: ***An R-2R Ladder is a simple and inexpensive way to perform digital – to – analog conversion, using repetitive arrangements of precision resistor networks in a ladder-like configuration. The application of Multisim for realizing R2R DAC bridges the gap between theory and the real circuits. This paper provides a detailed view of a 4 bit and an 8 bit R2R ladder with optimum accuracy by using Multisim. Experiments are performed on 4 bit and 8 bit R2R ladder with decade counter (staircase) and the accuracy of Theoretically experimented and Multisim experimented scenarios are compared. The comparison shows higher range of accuracy is obtained when R2R ladder is experimented in Multisim, Multisim offers additional features such as ease of implementation rebuild and cost reduction when compared to practical simulation of R2R ladder.***

Keywords: R2R Ladder, DAC, Staircase, Multisim, Counter

1. Introduction

Connecting digital circuitry to sensor devices is simple if the sensor devices are inherently digital themselves. Switches, relays, and encoders are easily interfaced with gate circuits due to the on/off nature of their signals. However, when analog devices are involved, interfacing becomes much more complex. What is needed is a way to electronically translate analog signals into digital (binary) quantities, and vice versa. An analog-to-digital converter, or ADC, performs the former task while a digital-to-analog converter, or DAC, performs the latter. An ADC inputs an analog electrical signal such as voltage or current and outputs a binary number. [1] In block diagram form, it can be represented as such:

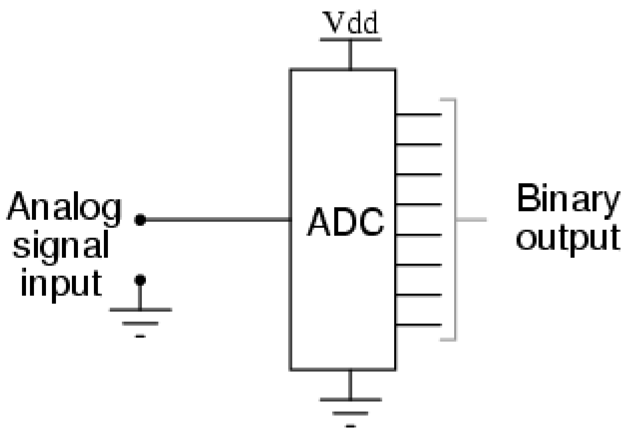

Figure 1: ADC **Block** Diagram

A DAC, on the other hand, inputs a binary number and outputs an analog voltage or current signal. In block diagram form, it is as follows:

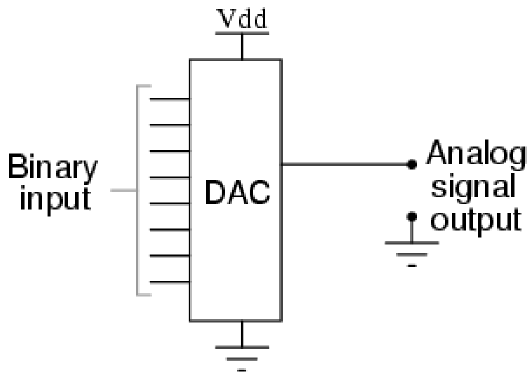

Figure 2: ADC Block Diagram

Together, they are often used in digital systems to provide complete interface with analog sensors and output devices for control systems such as those used in automotive engine controls:

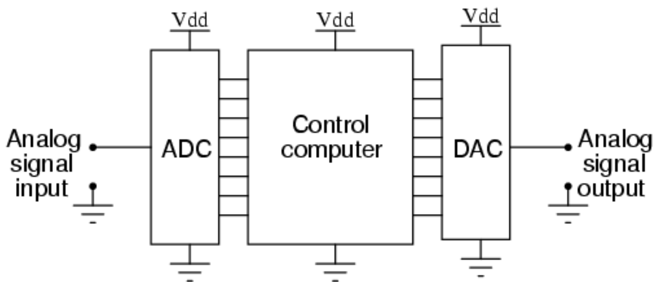

Figure 3: ADC – Processor – DAC

The digital data are entered through the 8 lines (D_0 to D_7) which is to be converted to an equivalent analog voltage (V_{out}) by the mean of the R/2R resistor network. Commercial Digital to Analog converter ICs are based on the similar principles. [1] The R/2R network is build by a set of resistors of two values, with values of one sets being twice of the other. In all of the circuits sets of 1K and 2K resistors are used, which is near to the R/2R ratio. Accuracy or precision of DAC depends on the values of resistors chosen, higher precision can be obtained with an exact match of the R/2R ratio.

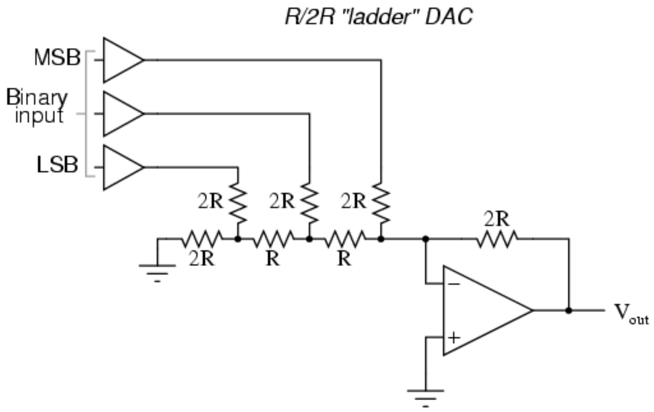

Figure 4: Normal 1- Bit Ladder circuit

2. Circuit, Multisim, Results and Design

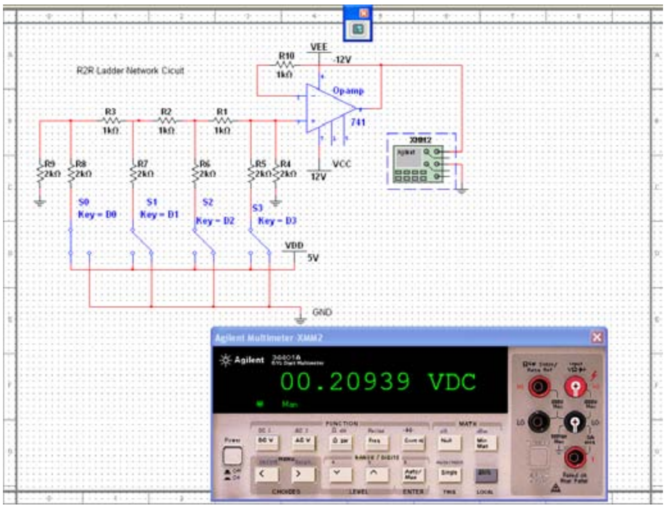

Figure 5: Schematic Diagram of 4bit DAC and output.

The Multisim simulator is software simulation tools which provide an accurate simulation of digital and analog circuit operations. Multisim allows us to grasp concepts quicker and gain deeper intuition for circuits. The operating system windows XP/ Vista / 64bit Vista and Windows supports fully to this Multisim software. It has been designed to help hardware designers' gain better understanding of circuit behavior. [2] Since the quality of simulation results is highly dependent on applied signals as well as analyzing and displaying simulation. It helps to close gap between design and practical test. It is easier to interface real world signal from inside Multisim and output data to drive real world circuitry, or display simulation data in a more suitable to form. Using this software it's possible to design projects before it is executed on real components. Multisim provides with an interactive oscilloscope, bode plotter, logic analyzer, power supply, multimeter, function generator, etc. to simulate and analyze the design. It trains creative thinking and innovative abilities. Therefore, the use of Multisim is able to meet the needs of the electronic experiment curriculum design.

3. Design Example 4 – Bit DAC (Case 1st and 15th)

Design Example (Figure 5) for 4-Bit R2R DAC circuit When three Digital Inputs are set to 0 that is D_3=D_2=D_1= means low state and D_1=1 means High state

If Vr = 5Volts

$$Vo = \frac{Vr}{24} = \frac{5X1}{24} = 0.20833Volts$$

For this case the Theoretical value is 0.20833 volts and experimental value using multisim is 0.20939 (Figure 5 and Table 1)

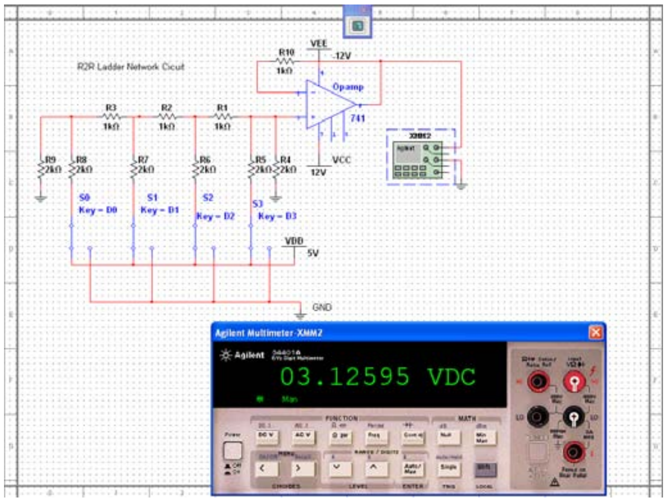

Figure 6: Schematic diagram and of 4bit DAC output

Table 1: R2R DAC (4 Bit) circuit Theoretical and Experimental readings.

4-Bit R2R DAC circuit Table of Readings						
	Digital Inputs				*Analog o/p Voltage*	
Decimal Equivalent	*D_3*	*D_2*	*D_1*	*D_0*	*Theoretical Value Vo*	*Experimental Value Vo (Multisim)*
1	0	0	0	1	0.20833	0.20939
2	0	0	1	0	0.41666	0.41771
3	0	0	1	1	0.62500	0.62604
4	0	1	0	0	0.83333	0.83436
5	0	1	0	1	1.04166	1.04269
6	0	1	1	0	1.25000	1.25102
7	0	1	1	1	1.45833	1.45934
8	1	0	0	0	1.66666	1.66767
9	1	0	0	1	1.87500	1.87600
10	1	0	1	0	2.08333	2.08432
11	1	0	1	1	2.29166	2.29265
12	1	1	0	0	2.50000	2.50097
13	1	1	0	1	2.70833	2.70930
14	1	1	1	0	2.91666	2.91763
15	1	1	1	1	3.12500	3.12595

When all the DigitalInputs are set to one (Figure 6 and Table 1) means High state that is D_3=D_2=D_1=D_0=1 then

$$Vo = \frac{Vr}{24} = \frac{5X15}{24} = 3.12500Volts$$

For this case theoretical value is 3.12500 volts and experimental value using multisim is 3.12595 similarly all other theatrical values have been calculated and shown in Table 1.

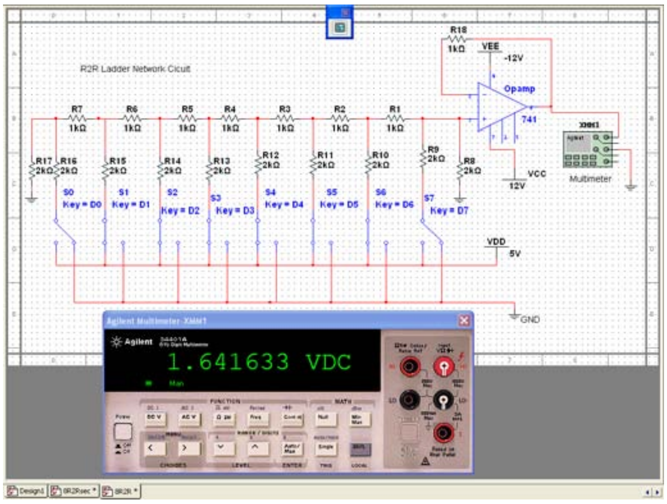

Figure 7: Schematic diagram of 8bit DAC 126th case output

Table 2: R2R DAC (8 Bit) circuit Theoretical and Experimental readings

Table of Readings										
Decimal Equivalent	Digital Inputs								Analog o/p Voltage	
	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Theoretical Values mVolts/ Volts	Experimental Values m Volts / Volts (Multi-sim)
0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	1	0.01302	0.01408
2	0	0	0	0	0	0	1	0	0.26041	0.27106
126	0	1	1	1	1	1	1	0	1.64062	1.64163
127	0	1	1	1	1	1	1	1	1.65364	1.65465
128	1	0	0	0	0	0	0	0	1.66666	1.66767
129	1	0	0	0	0	0	0	1	1.67968	1.68069
130	1	0	0	0	0	0	1	0	1.69270	1.69371
254	1	1	1	1	1	1	1	0	3.30729	3.30824
255	1	1	1	1	1	1	1	1	3.32031	3.32126

Design Example 8 – Bit Dac (Case 126 and 255)

Design Example (Figure 7 and Table 2) for 8 -Bit R2R DAC circuit When six Digital Inputs are set to 0 that is D_7 and D_0 =0 means low state and D_6=D_5=D_4D_3=D_2=D_1 =1 means High state

$$Vo = \frac{Vr}{2^8}\left(\frac{2R}{3R}\right) = \frac{Vr}{128X3}$$

$$Vo = \frac{Vr}{384}$$

$$Vout = \frac{VR}{384} = \frac{5X126}{384} = 1.64062 \text{ Volts}$$

For 126th case the Theoretical value is 1.64062 volts and experimental value using multisim is 1.64163 (Figure 7 and Table 2)

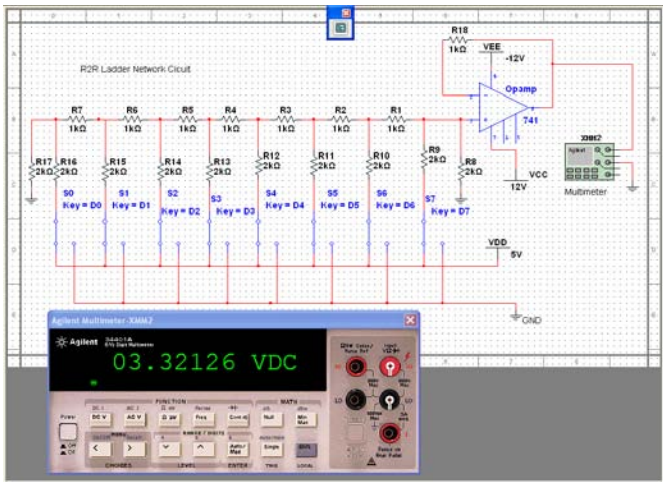

Figure 8: Schematic diagram and of 8bit DAC 255th case output

When all the Digital Inputs are set to one means High state that is D_7=D_6=D_5=D_4D_3=D_2=D_1=1 then

For 255th case the Theoretical value is 3.32031 volts and experimental value using multisim is 3.32126 (Figure 8) similarly same other theatrical values have been calculated and shown in Table 2

$$\text{Vout} = \frac{\text{VR}}{384} = \frac{5\text{X}255}{384} = 3.32031 \text{ Volts}$$

In Table 2 only few cases have been discussed and rest have been ignored due to larger decimal equivalent (ie 0 -255)

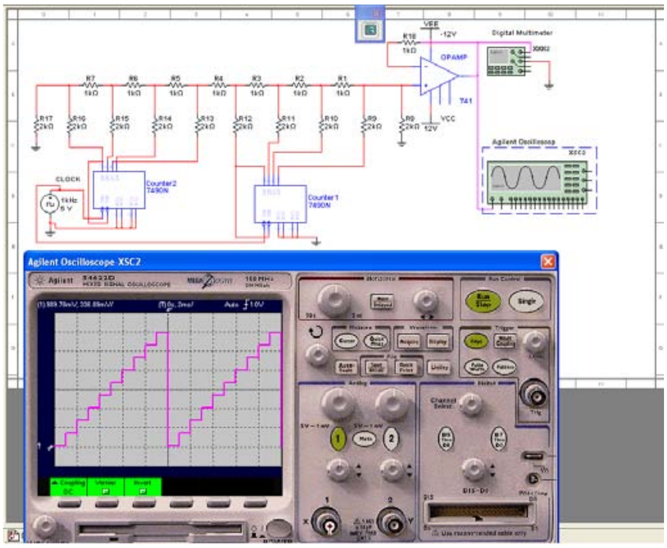

Figure 9: Schematic diagram of 8bit DAC with staircase output

The ideal input-output characteristic of a DAC is a staircase with uniform step size over the complete dynamic range [3]. As the counter (7490) counts up from 00000000 to 11111111 staircase waveforms will generated for each input clock pulse as shown in Figure 10 (b).

4. Components

a) **Opamp**

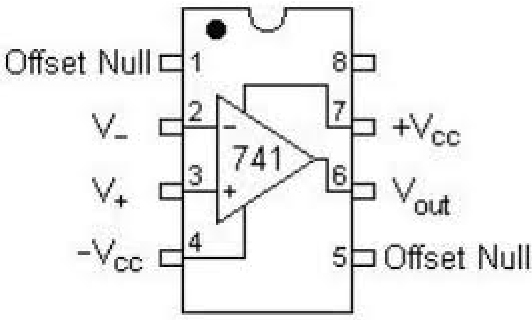

Figure 11: Opamp Block Diagram and Pindetails

Opamp µA741

The µA741 is a general-purpose operational amplifier featuring offset-voltage null capability. The high common-mode input voltage range and the absence of latch-up make the amplifier ideal for voltage-follower applications.[4] The device is short-circuit protected and the internal frequency compensation ensures stability without external components. A low value potentiometer may be connected between the offset null inputs to null out the offset voltage as shown in Figure 8. An op-amp has a single output and a very high gain, which means that the output signal is much higher than input signal. [5] An op-amp is often represented in a circuit diagram with the above symbol: (Figure 11)

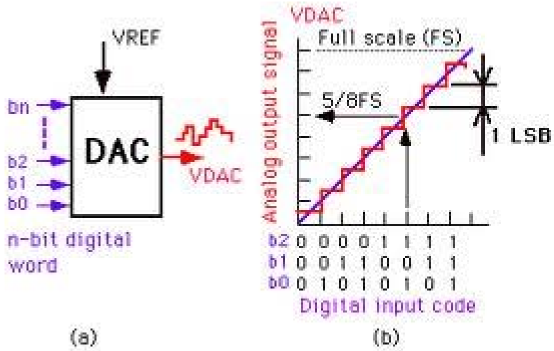

Figure 10: block diagram of DAC and staircase explanation

b) Counter

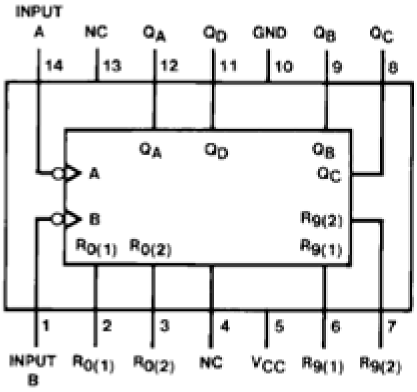

Figure 12: Counter (7490) Block diagram and Pin Details

DM 7490 Decad counter

The DM7490A monolithic counter contains four master slave flip-flops and additional gating to provide a divide-by two counter and a three-stage binary counter for which the count cycle length is divide-by-five. The counter has a gated zero reset and also has gated set to- nine inputs for use in BCD nine's complement applications. To use the maximum count length (decade or four-bit binary), the B input is connected to the QA output. The input count pulses are applied to input A and the outputs are as described in the appropriate Function Table. A symmetrical divide-by-ten count can be obtained from the counters by connecting the QD output to the A input and applying the input count to the B input which gives a divide by- ten square wave at output QA [6].

c) Change over switch

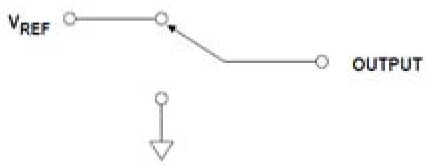

Figure 13: 1-Bit DAC: Changeover Switch (Single-Pole, Double Throw, SPDT)

A switch is a device for making and breaking the connection in an electric circuit i.e. switching an output between a reference and ground or between equal positive and negative reference voltages, as a 1-bit DAC as shown in Figure 13. A switch that uses a toggle joint with a spring to open or close an electric circuit as an attached lever is pushed through a small arc.

5. Conclusion

Most physical variables are analog in nature. Quantities such as temperature, pressure and weight can have an infinite number or values. Converting an analog value to a digital equivalent (binary number) is called digitizing the value. Such operation is performed by an Analog-to-Digital Converter (ADC). After processing the digital data, it is often necessary to convert the results of such operation back to analog values; this function is performed by a Digital-to-Analog converter (DAC).The Multisim simulator is a useful tool to perform theoretical and practical experiments to improve understanding of the various electronic concepts. It is also helpful to design and program embedded system applications in our further research work. It also can debug, execute verify results before real time implementation. Experiments were performed on 4 bit and 8 bit R2R ladder with decade counter (staircase), the accuracy of theoretical experimented and Multisim experimented scenarios are compared. Results shows higher range of accuracy is obtained when R2R ladder is experimented in Multisim,

Reference

[1] James Bryant, Walt Kester, “Data Converter Architectures”, Wiley publications, pp 3.1 -3.35, 24 may 2011.

[2] S. Mahata, A. Maiti,and C. K. Maiti, “Cost-EffectiveWeb-Based Electronics Laboratory Using NI MultiSim, LabVIEW and ELVIS II”, IEEE Journal, pp 242-243, 2010

[3] F. Maloberti, *Data Converters*, Springer, New York, NY, USA, 2007, ISBN 978-0-387-32485-2

[4] Texas instruments mA741, mA741Y “General-Purpose Operational Amplifiers” Slos094b –pp 1-10 November 1970 – Revised September 2000

[5] Bruce Carter and Ron Mancini, “Op Amps of every one”, 3rd edition, Chapter 18 pp 318 -322 Safari publications

[6] Fairchild semiconductor DM7490A Decade and Binary Counter DM7490A pp 1- 5August 1986 Revised July 2001.

Author Profile

Raghavendra.R received Diploma in electronics and Communication in the year 2000, and currently working in RV College of Engineering, Mysore road, Bangalore, Karnataka, India as a Instructor. His main research interests include electronic circuits design and debugging, Microcontroller, Genral perpose PCB designing, Networking, servicing, soldering and desoldering.

Dr Hariprasad S.A obtained his PhD from Avinashilingam University for Women, Coimbatore in the area of digital controllers’ .He is having teaching experience of 23 years and six years of research experience. He has published 35 papers in international national journals and conferences. He has also published a text book on advanced Microprocessor and reviewed books on Microwave engineering and won best teacher award (twice) from RSST and appreciation award from ISTE. His research areas of interest are embedded systems and RF systems.

Dr M. Uttarakumari received her B.E from Nagarjuna University in 1989 and M.Tech from Bangalore University in 1996 and Ph.D degree from Andhra University in 2007. She is currently HOD with the Department of Electronics and Communication Engineering, R.V. College of Engineering, Bangalore, India. Her current research interests include image compression, watermarking, digital signal processing.