DIGITAL TO ANALOGUE CONVERTER R/2R FOUR BIT TRAINER

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ABSTRACT

Digital to Analogue Converter (DAC) R/2R four bit trainer is a project that able to demonstrate the functions of switches and resistors which is able to convert digital signal to analogue signal. This trainer was constructed by using a Summing Amplifier and a set of resistors R and 2R as its inputs. A DAC trainer was built as an innovation for the subject Electronic Circuits as teaching aids for students to understand the learning process deeper especially in the practical class. In addition, there are so many advantages such as lightweight, accurate output, save time and reduce cost as well. This study involves the design and testing of a trainer board that can enable students to learn the basics and applications of digital to analogue converter as a means of supplementing their technical know-how of on how these devices are actually used in the field. The results show that the trainer board which designed is appropriate with the theorem.

Keywords: binary, digital, analogue, signals, trainer

1. Introduction

In the development of science and technology, all information processed must be accurate and fast. (David G.Alciatore and micheal B. Histand, n.d.) Since all the information around us is continuous, then a circuit that is capable of converting digital signals to analog signals needed. According to (Dsvakola, 2010) process of converting digital signal into equivalent analogue signal is called Digital to Analogue conversion. The electronics circuit, which does this process, is called Digital to Analogue converter. The circuit has 'n' number of digital data inputs with only one output.

The importance of Digital-to-Analog converters (DACs) is a direct consequence of the utilization of digital electronics. In many applications, digital circuits can only be utilized providing an appropriate translation, i.e. conversion, of their digital output information into the analogue world(Kherde & Gumble, 2013). The function of this translation is realized through DACs.

Nowadays, there are many trainers in electrical and electronic engineering field, varies from the very simple and inexpensive to the complex and sophisticated. Knowing this, DAC trainer was developed not only to reduce the cost but also to be used by lecturers as a teaching tool. Besides, students also can refer the correct waveform when doing their practical work. According to (Fuada, 2016); based learning activity is an activity to prove the truth of a theory delivered by lecturers / teachers in learning activities. Trainer board is created as an effective teaching media to help improve students' motor skills in learning the conversion of Digital signal to Analogue signal while also building the ability of learners to be able to work in groups.

Training boards have become essential in practical learning in the field of electronics (Avelino, Santos, Danoso, Gumapac, & Vicedo, 2015). Since the Digital to Analogue training module is not available in the laboratory of Polytechnic Tuanku Sultanah Bahiyah, the creation of such a module would be very beneficial to the students. It is this for reason that the lecturers thought of designing and testing a training board that would enable the students to experience hands-on applications of on how conversion of digital signals to analogue signals occur; and to appreciate the importance of this device in the field of electronic engineering. This training module would not only guide the students to the connections of the circuit proper but also, to the analysis of each circuit. Since the knowledge of how to use DAC is crucial to the training of electronics engineering students, having a trainer on how to use and implement this device would be very useful and helpful and efficient in an electronics engineering laboratory.

2. Literature Review

A Digital to Analog Converter plays an important role digital signal processing. The DAC converts a digital code to an equivalent analogue signal such as a voltage, current, or electric charge. Signals can easily be stored and processed in digital form; a DAC is used for the signal to be recognized by human senses or non-digital systems.

2.1. DAC Block Diagram

A digital to analogue converter (DAC) is a device that converts digital signals number (binary) to analogue signal such as voltage or current output(Maria II, 2017).

2.1.1. Digital to Analogue Converter (DAC), 4 bit binary weights consists of four major components(Lee, 2012)

- n switches one for each bit applied to the input
- a weighted resistor ladder network, where the resistance are inversely proportional to the numerical significance of the corresponding binary digital
- a reference voltage Vref
- a summing amplifier that adds the current flowing in the resistive network to develop a signal that is proportional to the digital input
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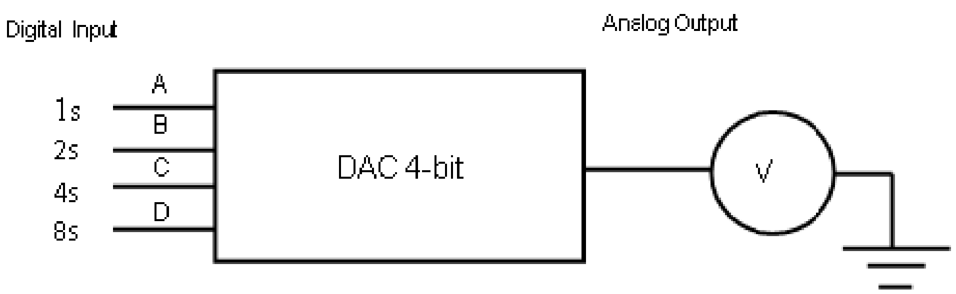

Figure 1: Basic DAC block diagram(Radulov, Quinn, Hegt, & van Roermund, 2011)

2.2. In DAC block diagram it include resistor network and summing amplifier circuit. There are two part of DAC which are resistor network and summing amplifier as shown in figure 2.2 below

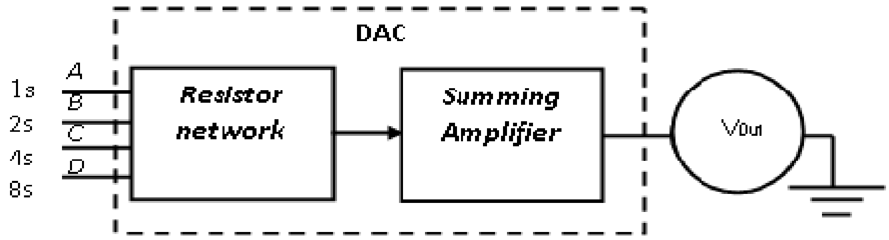

Figure 2 :Resistor network and summing amplifier(Horowitz, Paul; Hill, 2000)

2.3

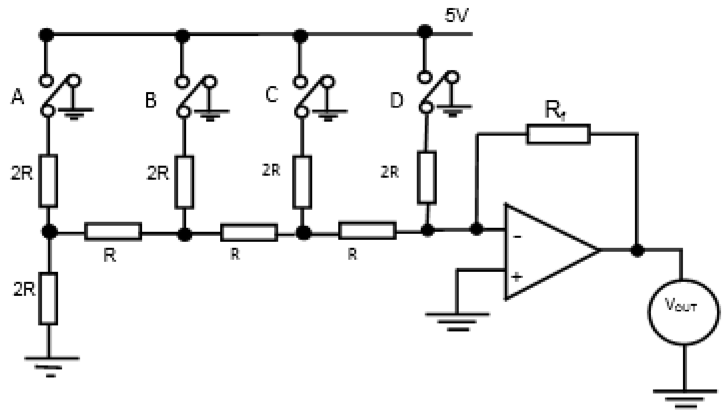

Figure 3: DAC R/2R 4-bit(Perrott, 2011)

Figure 3 shows the connection of DAC R/2R 4 bit, which constructed, as its name indicates, out of two values of resistors. A modification of the weighted resistor DAC is uses only 2 different resistances which are R (1K) and 2R (2K).Voltmeter reading is determined by the binary number ABCD and the resistor weights.

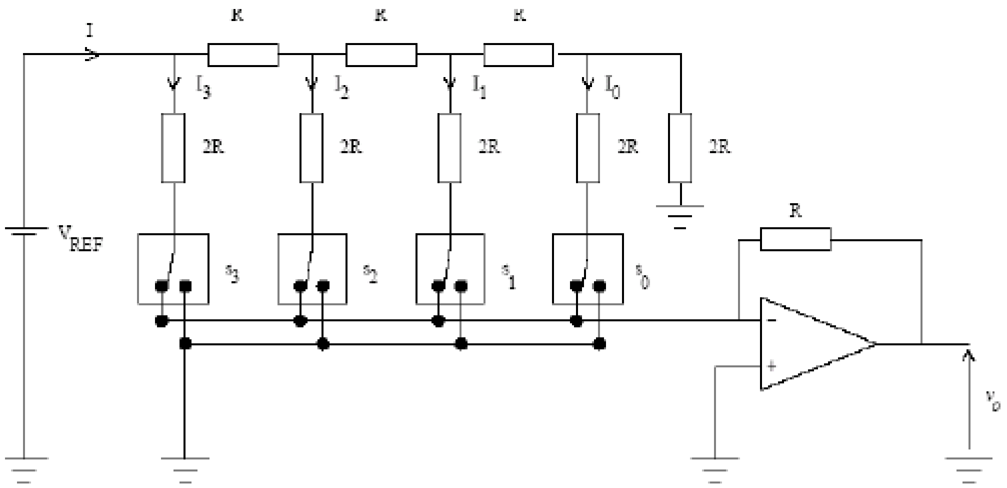

Figure 4: An R-2R ladder 4-bit D/A converter(Radulov et al., 2011)

2.3.1

The trick to analysing the R-2R ladder network is to start from its right-hand end: As shown in Figure 4 at this end of the system there are two 2R resistors acting in parallel which combine to form an effective resistance R. This effective resistance then appears in series with another resistance R to form a resistance of 2R. However, this effective resistance of 2R is in parallel with another resistance 2R. Thus at each stage of the analysis of the ladder network, all elements to the right of a particular node are equivalent to a resistance of 2R.

2.3.2 The analysis of the ladder network means that for the network in figure 4 the incoming current splits into two at each node and thus

$I_2 = 2I_1 = 4I_0$ and (1)

$I_3 = Vref/2R = 2I_2 = 4I_2 = 8I_0$ (2)

Then the general expression for the circuit also can be obtained by equation;

$$V_{out} = \frac{\mathbf{V_{ref}}}{\mathbf{2^n - 1}} \times \mathbf{B_{in}} \times \frac{\mathbf{R_f}}{\mathbf{R}}$$

Where n = number of bits and B_{in} = digital input converted to decimal numbers.

2.3.3

Each bit B_n of the digital code controls a switch S_n. When $B_n = 1$, the switch S_n directs current I_n towards the summing junction; otherwise the current flows straight down to ground. The DAC output voltage is therefore determined by a current that is proportional to the weighted sum of the input bits as required.

2.3.4

The advantage of this architecture is that the inverting input of the op-amp is a virtual earth and hence one end of each the 2R resistors is always connected to 'earth'(Rosa, 2010). This means that the current flowing through each branch of the ladder network is independent of the switch conditions and hence the digital input. The significance of this is that it means that the total current supplied by the voltage source is constant and the circuit performance is independent of the output impedance of the voltage source.

3. Methodology

The system was developed as a reference material and teaching tools for the lecturers during the process of teaching and learning. In order to develop the system there are several aspects play an important role such as working step, circuit design, printed circuit board (PCB) layout, source materials, implementing, testing and improvements.

3.1. Implementation

Firstly, the schematic diagram for this trainer was prepared by using Proteus software. Then the schematic diagram was transferred to PCB layout. After that, the normal process such as etching, drilling, placing the components and soldering were successfully done.

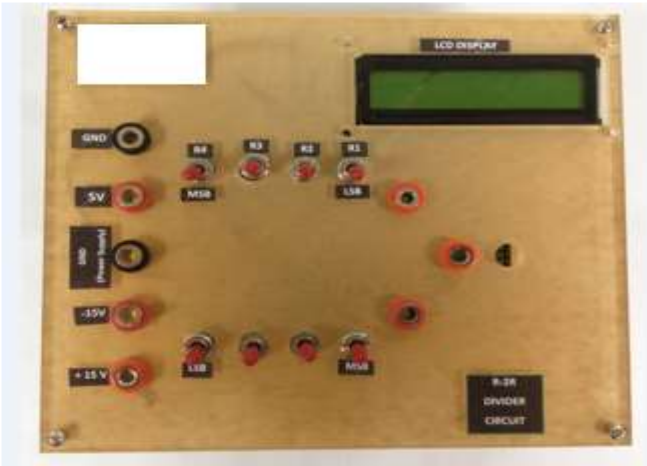

Figure 5. R/2R trainer

3.2 Application

The trainer was provided with appropriate labels such as input selection, input switch (binary), selection switch, probe point and LCD to display output to help the lecturers using this trainer correctly. This trainer used +15V and -15V as supply voltage while LCD used to display desired output.

3.3 Components

3.3.1 Resistor

Resistor which is the type of passive electronic components are extensively used in electronic circuits. There are impossible to build an electronic circuit without involving resistors. Basically the function of a resistor is always to oppose the flow of current through it and strength of this opposition is termed as its resistances. Many types of resistors are used having different uses and construction(Coates, 2015). This trainer consists of only 2 resistors with each of it values are 1K and 2K.

3.3.2 Operational Amplifier (LM741)

An operational amplifier is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. In this configuration, an op-amp produces an output potential (relative to circuit ground) that is typically hundreds of thousands of times larger than the potential difference between its input terminals(Bakshi, 2009). Operational amplifiers had their origins in analog computers, where they were used to perform mathematical operations in many linear, non-linear and frequency-dependent circuits. The amplifiers 741 offer many features which make their application nearly fool proof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations(Tocci & Widmer, 2001).

4. Result

The trainer was successfully developed and tested. It shows that the analogue output produced were almost same to the theory. Figure 6 shows the connection of DAC trainer while table 1 shows the comparison between theoretical and experimental result. It proved that this trainer can produce the output voltage which closely to the theory.

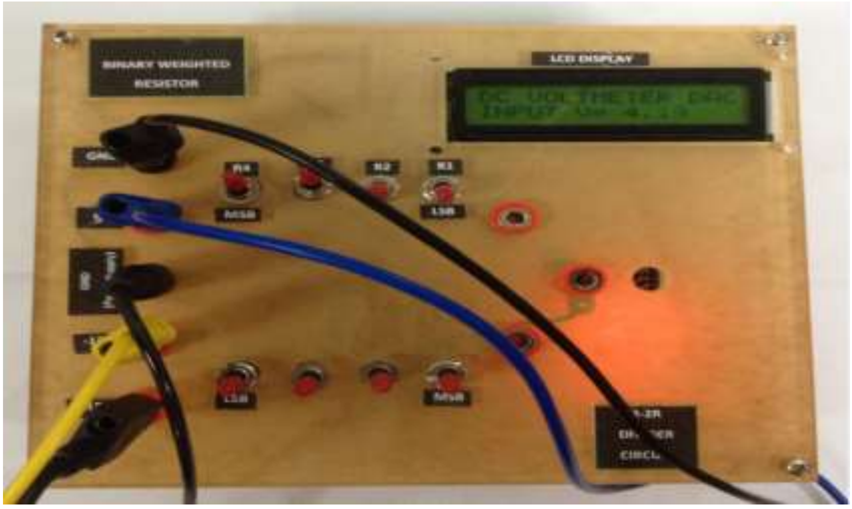

Figure 6: Connection for R/2R trainer

4.1 Comparison between Theoretical Value and Practical Value

Table 1 and table 2 show the comparison value of Vout between theoretical and practical value which has been tested few times in the laboratory during practical class.

Table 1. Theoretical Value

Input				Output, V_{OUT}
D	C	B	A	$V_{OUT}=\frac{V_{ref}}{2^n}\frac{R_f}{R}B_{in}=\frac{5}{2^4}\frac{R}{R}B_{in}=\frac{5}{16}B_{in}$
0	0	0	0	0
0	0	0	1	0.3125
0	0	1	0	0.6250
0	0	1	1	0.9375
0	1	0	0	1.2500
0	1	0	1	1.5625
0	1	1	0	1.8750
0	1	1	1	2.1875
1	0	0	0	2.5000
1	0	0	1	2.8125
1	0	1	0	3.1250
1	0	1	1	3.4375
1	1	0	0	3.75
1	1	0	1	4.0625
1	1	1	0	4.375
1	1	1	1	4.6875

Table 2. Practical Value

Input				Output, V_{OUT}
D	C	B	A	$V_{OUT} = \frac{V_{ref}}{2^n}\frac{R_f}{R}B_{in} = \frac{5}{2^4}\frac{R}{R}B_{in} = \frac{5}{16}B_{in}$
0	0	0	0	0
0	0	0	1	0.3365
0	0	1	0	0.7150
0	0	1	1	0.9415
0	1	0	0	1.1700
0	1	0	1	1.5152
0	1	1	0	2.0050
0	1	1	1	2.1875
1	0	0	0	2.4770
1	0	0	1	2.8111
1	0	1	0	2.9110
1	0	1	1	3.3371
1	1	0	0	3.75
1	1	0	1	4.0633
1	1	1	0	4.341
1	1	1	1	4.6811

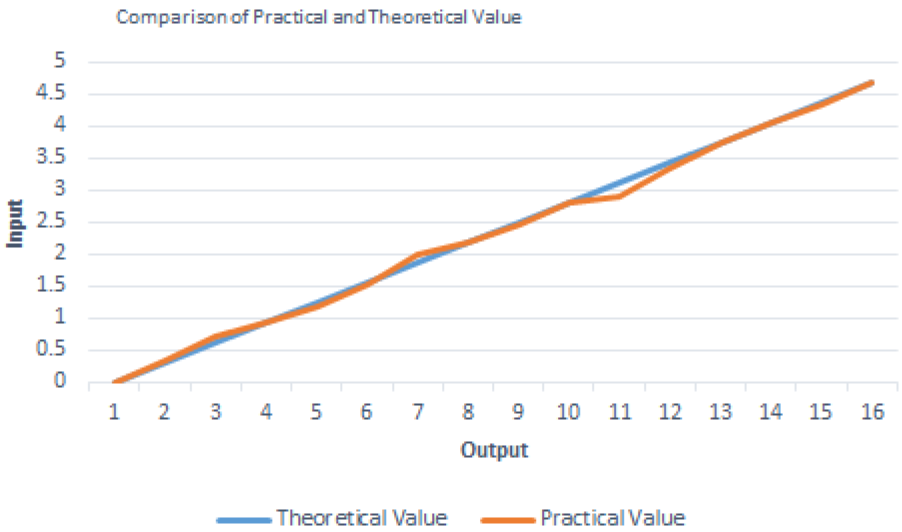

Figure 7: Comparison between practical and theoretical value

By using formulae for percentage error;

$$\% \text{ error} = \frac{Experimental - Theoretical}{Theoretical} \times 100\%$$

Table 3. Percentage error between theoretical and practical values

Input				Percentage Error (%)
D	C	B	A	$\frac{Practical - Theoretical}{Theoretical}$ x 100%
0	0	0	0	0
0	0	0	1	0.080
0	0	1	0	0.140
0	0	1	1	0.004
0	1	0	0	0.060
0	1	0	1	0.030
0	1	1	0	0.070
0	1	1	1	0
1	0	0	0	0.009
1	0	0	1	0.0005
1	0	1	0	0.070
1	0	1	1	0.030
1	1	0	0	0
1	1	0	1	0.0001
1	1	1	0	0.008
1	1	1	1	0.002

Based on the graph in *figure 7* and calculation of percentage error in Table 3, it is proven that this trainer is suitable and precise to use in the practical class since the value of percentage error only ranges from 0-0.014% which is very small. The results show that the trainer board which designed is appropriate with the theorem. The value of Vout for practical quite closer to the theoretical value but still cannot get accurate result as theory did. This differences may be because, since in practice, the analogue signal is not a precise reconstruction and the filter has finite phase delay. Therefore, quantization errors occurred. The output voltage of this circuit also cannot change very fast since it is limited by the **slew rate** of the op amp. (Slew rate is a measure of how fast the output voltage can change, and it is in units of V/sec.). Large values of resistors also one of the factor which difficult to realize and implement.

5. Conclusion

The trainer was successfully developed to fulfil its objective of facilitating the lecturers and students to monitor the process of converting digital signal to analogue signal. From experimental results, collected results proved that the output produced by this trainer almost similar to the theory. Instead of capable to demonstrate the application of converting digital signal to analogue signal, this DAC also provides several advantages such as lightweight, accurate output, save time and save costs as well. By small value percentage error which is 0 – 0.14%; and the value measured also quite closer to the theoretical value; this paper concludes that this trainer is precise and suitable for the used by lecturers as a teaching tool.

Future Work

In this paper 4-bit R-2R DAC is designed, this can be increased further and power dissipation can also be reduced.

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