CONTROL AND COMPUTER APPLICATIONS - EEP311

COMPREHENSIVE REVIEW ON DIGITAL TO ANALOG CONVERTERS: FROM FUNDAMENTAL PRINCIPLES TO ADVANCED ICS

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1 Introduction

The report explores Digital to Analog Converters (DACs) with a specific emphasis on two types: Binary-Weighted Resistor (BWR) and R-2R ladder architectures. The DAC 7821 IC, featuring the R-2R ladder, is a central focus. This investigation aims to elucidate the principles, distinctions, and applications of these DAC types in contemporary electronic circuits.

2 Binary-Weighted Resistor (BWR)

2.1 Basic Principle:

Utilizes weighted resistors and an inverting amplifier op-amp. Each resistor represents a digital bit, converting it into an analog form. Works from the Least Significant Bit (LSB) to the Most Significant Bit (MSB).

2.2 DAC Working:

Takes digital input, transforms it into proportional analog output. Output voltage depends on the binary code input. Involves a summing operational amplifier and weighted resistors.

2.3 Resolution and Step Size:

2.3.1 Resolution:

Resolution is a fundamental parameter that defines the ability of a DAC to represent a range of analog value

$$Resolution = 2^n \tag{1}$$

2.3.2 Step Size:

Step size is the smallest change in output voltage that a DAC can produce. It represents the difference between two consecutive voltage levels of the DAC. The relationship between resolution (R) and step size is given by:

$$StepSize = \frac{V_{ref}}{2^n} \tag{2}$$

2.4 Summing amplifier configuration.

A summing amplifier adds weighted input voltages to produce an output voltage. Binary input is applied through digital switches, each corresponding to a bit in the binary code. These switches alter the reference voltage seen by the summing amplifier, influencing the output.

2.4.1 BWR Circuit

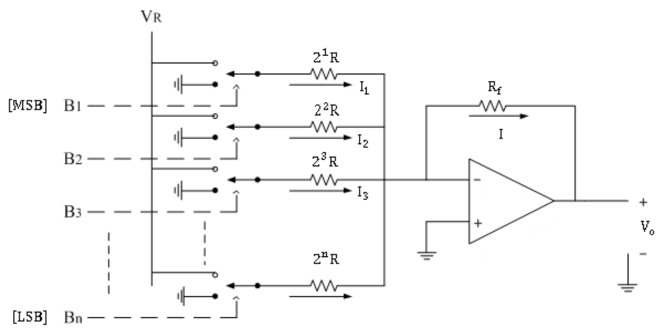


Figure 1: Binary-Weighted Resistor Circuit

2.4.2 Output Voltage Formula

$$V_{out} = R_f \cdot I_0 \tag{3}$$

as:

$$I_0 = V_{ref} \sum_{i=1}^{N} \frac{b_i}{2^{i-1}R} \tag{4}$$

also:

$$V_{out} = -V_{ref}(B_0 \frac{R_f}{R_0} + B_1 \frac{R_f}{R_1} ... + B_{n-1} \frac{R_f}{R_n - 1}) \tag{5}$$

2.4.3 Example:

For a specific scenario with a 4-bit DAC and given parameters:

- $V_{\text{ref}} = 5\,\text{V}$, Binary code: 1011

  The calculated output voltage (V_{out}) is given by the formula:

$$V_{\text{out}} = -5 \left(1 \cdot \frac{1}{2^3} + 0 \cdot \frac{1}{2^2} + 1 \cdot \frac{1}{2^1} + 1 \cdot \frac{1}{2^0} \right) \tag{6}$$

$$V_{\text{out}} = -5 \left(\frac{1}{8} + 0 + \frac{1}{2} + 1 \right) \tag{7}$$

$$V_{\text{out}} = -6.875\,\text{V} \tag{8}$$

2.5 Drawbacks and Advantages

2.5.1 Drawbacks

- Precision challenges for higher-order DAC, Temperature-dependent stability.

2.5.2 Advantages

- Simple assembly, Fast conversion speed, Straightforward circuitry.

3 The R-2R ladder network

3.1 4-bit R-2R Circuit

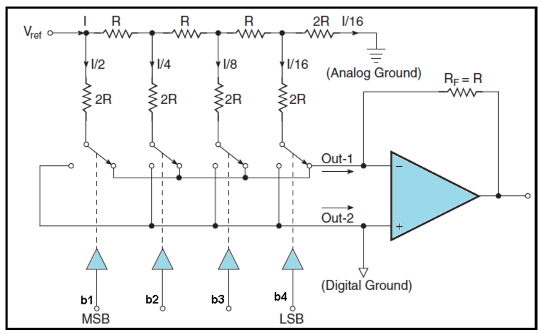


Figure 2: 4-bit R-2R Resistive Ladder Network

3.2 Working Principle

The R-2R ladder network operates on the principle of superposition and linearity. Each bit of the digital input contributes to a fraction of the total output voltage. The binary-weighted structure simplifies the design and ensures accurate conversion.

3.3 Output Voltage Formula

The output voltage (V_{out}) in an R-2R ladder DAC is given by the equation:

$$V_{\text{out}} = -V_{\text{ref}} \left(1 - \frac{1}{2^n} \right)$$

This formula illustrates the relationship between the output voltage, reference voltage (V_{ref}), and the number of bits (n) in the DAC. As the number of bits increases, the output voltage approaches $-V_{\text{ref}}$, providing a valuable insight into the DAC's resolution.

3.4 4-bit R-2R Ladder Example

Consider a 4-bit R-2R ladder network with a reference voltage $V_{\text{ref}} = 5\,\text{V}$. The output voltage ($V_{\text{out}}$) is given by the formula:

$$V_{\text{out}} = -5\left(\frac{B_0}{2^0} + \frac{B_1}{2^1} + \frac{B_2}{2^2} + \frac{B_3}{2^3}\right)$$

For a binary input of 1011, the calculated output voltage is:

$$V_{\text{out}} = -5\left(\frac{1}{1} + \frac{1}{2} + \frac{0}{4} + \frac{1}{8}\right)$$

$$V_{\text{out}} = -5\,(1 + 0.5 + 0 + 0.125)$$

$$V_{\text{out}} = -6.625\,\text{v}$$

3.5 Advantages

- Reduced component count compared to other DAC architectures, Easy scalability for different resolutions.

3.6 Disadvantages

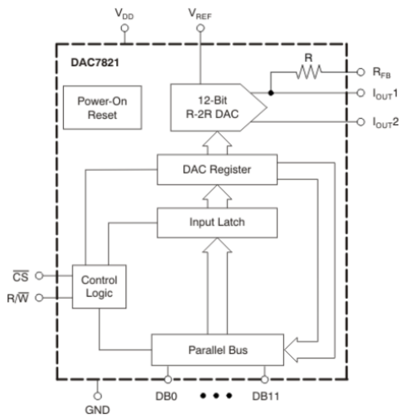
- Limited to low to medium resolutions, Requires precision resistors for accurate conversion.

4 DAC7821 Integrated Circuit (IC)

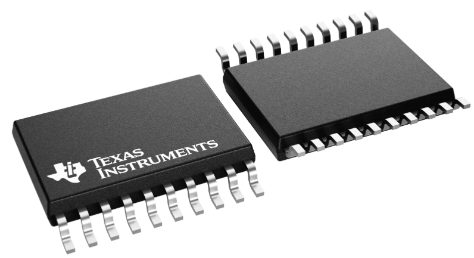
4.1 Overview

The DAC7821 is a 12-bit Digital to Analog Converter (DAC) IC that utilizes the Binary-Weighted Resistor (BWR) architecture. It offers high precision and is commonly used in applications where accurate analog voltage outputs are required.

4.2 Operation Overview



(a) from Texas Instruments Data sheet



(b) SMD

Figure 3: DAC7812

The DAC7821, a 12-bit DAC IC, employs an R-2R ladder network in conjunction with internal registers. Digital input codes are written to the Input Register, latched for stability, and processed through the ladder for analog conversion. Control bits in the Control Register manage operational modes, enabling precise analog output voltage control.

4.3 Key Features

- Resolution: 12 bits, Binary-Weighted Resistors.
- Fast Settling Time, Low Power Consumption.
- Wide Voltage Range.

4.4 Applications

The DAC7821 finds applications in various fields, including industrial automation, audio systems, and instrumentation.