Digital to Analog Conversion

Department:	Computer Science
Course:	Computer Architeture
Year:	2017/2018
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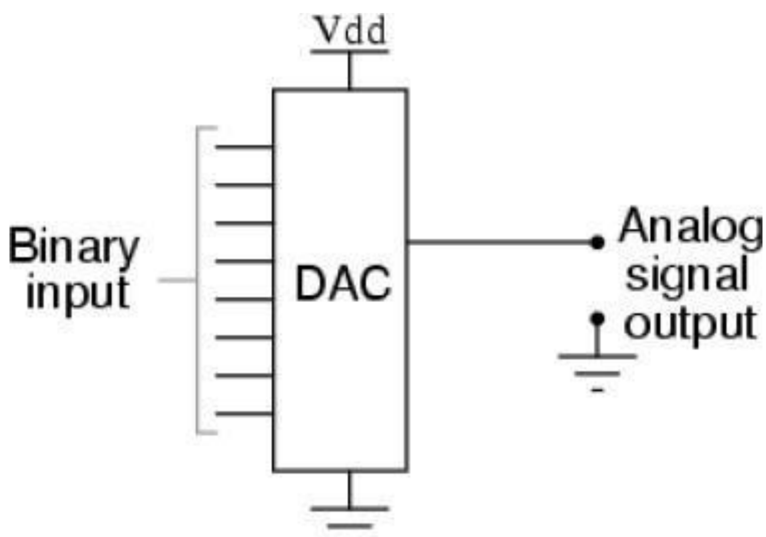
Introdution

The importance of Digital-to-Analog converters (DACs) is a direct consequence of the utilization of digital electronics.
A digital-to-analog converter (DAC or D-to-A) is a device for converting a digital (usually binary) code to an analog signal (current, voltage or charges).
Digital-to- Analog Converters are the interface between the abstract digital world and the analog real life. Simple switches, a network of resistors, current sources or capacitors may implement this conversion..
Depending on the specific applications, there are various types of DAC such as Binary Weighted DAC,R2R Ladder DAC,Segmented DAC, Hybrid DAC,PWM Dac,Multiplying Dac.The resolution bits, conversion time, reference voltage, conversion structure , type of output signal are the most caratheristics that determine whether is usefull for this porpuse or note.
This work will explain step by step how those types of dac work and are implemented.

Description of the DAC functionality

Basically, D/A conversion is the process of taking a value represented in digital code (such as straight binary or BCD) and converting it to a voltage or current which is proportional to the digital value.The arguments of this process are digital data, reference clock and reference amplitude (unit). The output of the D/A function isthe DAC analog output signal. The input signal is discrete in time and quantized in amplitude, coded in digital bits. The time-reference for the DAC is provided by its input clock signal. In most cases, the DACs are synchronized, requiring a separate clock input. However, there are some cases of asynchronous DACs, which interpret the time-reference through the change of the input digital data. In both cases, the output analog signal is continuous in time with quantized amplitude. The quantization of the output signal amplitude depends on the resolution of the digital input signal and that of the DAC.

The Figure F1 shows the generical example of it.



The equation that defines this process is:

Analog output = K × digital input

where **K** is the proportionality factor and it is constant value for a given

DAC. The analog output can of course be a voltage or current. When it is a voltage, **K** will be in voltage units, and when the output is current, **K** will be in current units. For the DAC of **K**=1 V, so that VOUT = (1 V) × digital input
We can use this to calculate VOUT for any value of digital input. For example, with a digital input of 11002= 1210, we obtain VOUT = 1V × 12 = 12V

Types of DAC

1- **The R2R Ladder DAC,** which is a binary weighted DAC that creates each value with a repeating structure of 2 resistor values, R and R times two. This improves DAC precision due to the ease of producing many equal matched values of resistors or current sources, but lowers conversion speed due to parasitic capacitance.

2- **The Segmented DAC,** which contains an equal resistor or current source segment for each possible value of DAC output. An 8-bit binary-segmented DAC would have 255 segments, and a 16-bit binary-segmented DAC would have 65,535 segments. This is perhaps the fastest and highest precision DAC architecture but at the expense of high cost. Conversion speeds of >1 billion samples per second have been reached with this DAC.

3- **Hybrid DACs,** which use a combination of the above techniques in a single converter. Most DAC integrated circuits are of this type due to the difficulty of getting low cost, high speed and high precision in one device.

4- **Multiplying digital-to-analog converters** (MDACs) produce a (current) output signal that’s a product of the given reference voltage and the code (i.e., a string of 0s and 1s) flowing through it. All data converters require a voltage reference (V_{REF}) and a typical, standard DAC needs a very stable fixed reference voltage in order to operate properly.

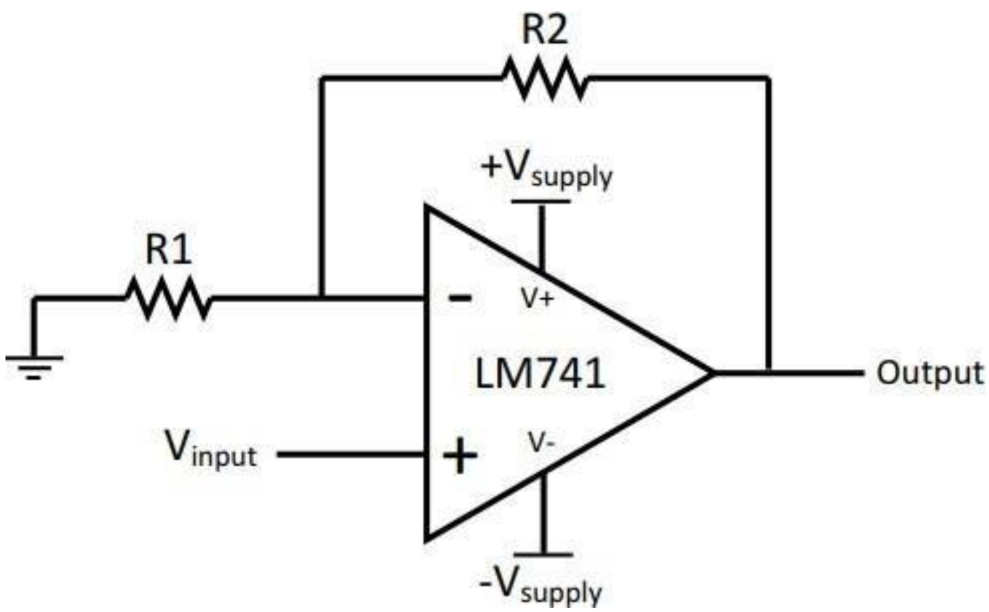
5- The **pulse_width_modulator**, the simplest DAC type. A stable current or voltage is switched into a low-pass **analog filter** with a duration determined by the digital input code. This technique is often used for electric motor speed control, but has many other applications as well.

R2R Ladder DAC

The binary-weighted-resistor DAC employs the characteristics of the inverting summer Op Amp circuit.

In this type of DAC, the output voltage is the inverted sum of all the input voltages:

The Figure F2 Operational Amplifier.



The output equation of this op- amp circuit:

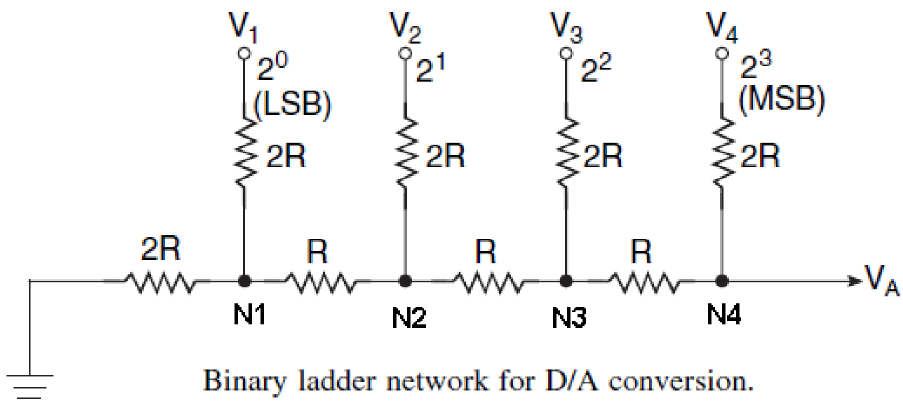
$$\text{Output} = -v_{in} * \frac{R1}{R2} .$$

An enhancement of the binary-weighted resistor DAC is the R- 2R ladder network.
This type of

DAC utilizes Thevenin‘s theorem in arriving at the desired

output voltages. The R-2R network
consists of resistors with only two values - R and 2xR.

The Figure F3 shows the an example of Binary R 2 R Ladder DAC.



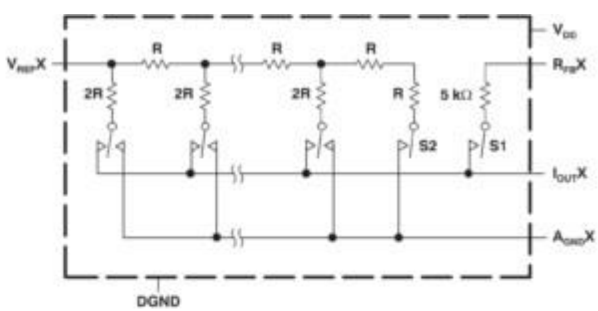
Binary ladder network for D/A conversion.

Due the successive division the bit that are to the left , the **LSB (lowest Significative bit)** contributes less and the **MSB(most significative bit) contributes more**.

What is a multiplying DAC?

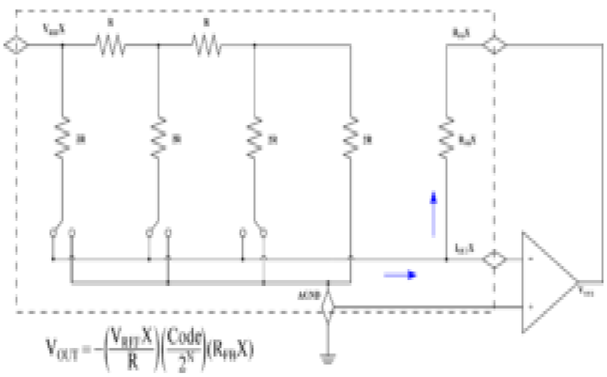
Multiplying digital-to-analog converters (MDACs) produce a (current) output signal that's a product of the given reference voltage and the code (i.e., a string of 0s and 1s) flowing through it. All data converters require a voltage reference (V_{REF}) and a typical, standard DAC needs a very stable fixed reference voltage in order to operate properly. However, the Multiplying Digital-to-Analog converter (MDAC) is a low-noise, precision DAC that uses a *varying* reference voltage. MDACs are often used in test and measurement equipment and other applications that require low noise. $V_{REF}X$ $I_{OUT}X$.

The Figure F4 shows one equivalent MDAC channel of the TI DAC8812 (digital connections omitted for clarity), containing two current-steering R-2R ladder DACs. The RFBX pin is provided as a matching feedback resistor for connection to the inverting input of an external I-to-V op amp. (Source: DAC8812 Datasheet, Texas Instruments.)



Typically, analog devices like op amps and data converters have input, output, and reference voltages (for data converters) that are bounded by the "rails" set by the device's supply voltage (Vs). The MDAC is an exception, as it can use a V_{REF} that is much higher than the voltage supplied to the MDAC itself. The external V_{REF}, then, determines the full-scale output for an MDAC, not V_S. Another difference between MDACs and fixed-reference DACs is that MDACs produce output as a current signal rather than a voltage output. This is easily remedied with a **current-to-voltage converting op amp** following the MDAC to provide a voltage signal output.

The Figure F5 shows an MDAC with an I-to-V operational amplifier and matched, integrated feedback resistor (Credit: K. C. Reese, III).



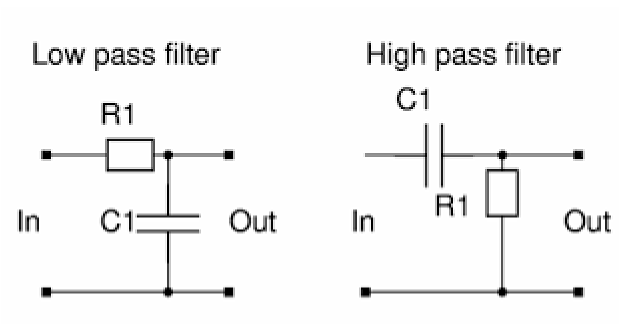
Another property of MDACs is that the reference impedance stays constant regardless of how the V_{REF} varies. That's right, the impedance of the MDAC measured at the V_{REF} pin stays constant regardless of the inputs to the MDAC or the value of the V_{REF}. The impedance of the MDAC output *does* vary with the code that is passing through the MDAC. The output current of the MDAC varies with the code flowing through the DAC. Therefore, looking at Figure 5, you can calculate the current at $I_{OUT}X$ if you know the code traveling through the DAC and the equivalent series resistance in the DAC from V_{REF} using Kirchoff and Ohm's laws.

It's important to note that the output impedance of the MDAC is going to vary with the code-dependent current flowing out of the I_{OUT} pin. This poses potential issues for the flowing I-to-V converting op amp. The RFBX internal to the MDAC is matched to the impedances in the MDAC, which helps, but the I-to-V converting op amp should have low offset voltage to avoid introducing linearity errors, because offset voltage in the op amp will be affected by the changing impedance it's getting at the I_{OUT} pin.

MDACs are used in several applications. For instance, if you have a digital design where you need to create an analog output with a fixed DC voltage as your resource. The MDAC can generate a waveform. An MDAC can also change the polarity and the amplitude of an AC signal. MDACS are known for precision (as long as they are paired with a precision or high-precision op amp). Major U.S. manufacturers of MDACs include Analog Devices and Texas Instruments.

In the MCU application environment, system designers can have DAC functionality nearly free of charge. PWM DACs are widely used in very low-cost applications, where accuracy is not a primary concern.
That explain the technique for converting a PWM pulse to an analog voltage using a simple RC low-pass filter. It also reviews the PWM DAC's limitations and its key design constraints with regard to resolution, frequency, ripple, settling time and current consumption, which are very important design parameters that are largely affected by the resistor (R) and capacitor (C) values, as well as the PWM duty cycle and frequency.

The Figure F6 shows the general RC-filter: low pass filter Vs high pass filter.



The RC-filter consists in two connected components one resistor and one capacitor.
The difference between low pass filter and high pass filter is the position of those two components .
The RC high pass filter the V_o ,**output voltage**, depends on the capacitor value and the V_I ,**input voltage** depends on the resistor value.
In the second one it's the opposite.

How PWM DACs Work

The MCU outputs a PWM signal to an RC low pass-filter. The PWM pulse train's digital value becomes an analog voltage, when it passes through the RC filter. At a given period of time, the analog output is proportional to the PWM pulse's high durations.

We can achieve digital-to-analog conversion by using firmware or hardware to vary the PWM duty cycle according to the following relationship:

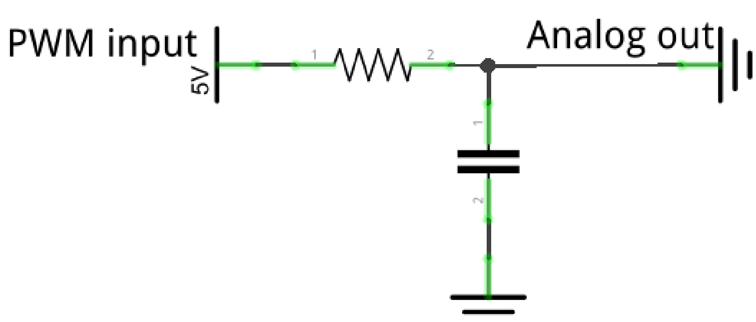
$$\text{desired DAC voltage} = A \times \text{duty cycle}$$

where A (for “amplitude”) is the logic-high voltage.

A PWM signal is defined as a digital signal with a fixed frequency, but a varying duty cycle.. The PWM period (T) is the time interval required to complete one full PWM cycle. The duty cycle is the ratio of the high duration (t) to the total period (T).

The PWM signal and RC-filter circuit parameters affect the analog output’s resolution, amplitude, settling time and ripple. The PWM DAC’s limitations are clearly demonstrated by analyzing the interaction of the PWM parameters and the RC filter. A better understanding of the relationship between these parameters enables designers to optimize the PWM to best suit their application’s requirements, while minimizing design time.

The Figure F7 shows RC-filter PWM DAC.



PWM DAC Bit Resolution

The PWM counter length (L) and the smallest duty-cycle change in the PWM counter (C) determine the PWM DAC's bit resolution.
For example, if the system generates an analog output voltage from a PWM DAC with a counter of 4,096 (L) and a minimum count step of one (C), the PWM DAC's bit resolution is 12 bits.
When the PWM resolution is determined, it is possible to calculate the Least Significant Bit (LSB) size. The LSB size is dependent upon the PWM resolution and the PWM's output-high level voltage (V_{OH}) .
For example, a 12-bit PWM DAC with a V_{OH} of 5V has an LSB size of 1.2 mV.

RC-Filter Design Considerations for PWM DACs

One key design consideration when determining the PWM's resolution is output-voltage ripple. Ripple occurs due to overshoot and undershoot as the PWM charges and discharges the RC circuit.

PWM DACs and Power Consumption

Many electronic products today are portable or handheld devices. These devices are battery-powered and many have strict constraints with regard to power consumption. Therefore, it is a good idea to minimize the PWM DAC's power consumption. The current consumed in the PWM solution is simple to approximate.
Another factor to consider is the filter's pole. As the resistor value increases, the 3 dB frequency decreases by the same magnitude. This can be compensated for by reducing the capacitor value by the same magnitude, which offsets the increased settling time and maintains the original pole of the filter.

Comparison Dac's type table

Parameters	**R2R Ladder**	**MDAC**	**PWM**
Alternating Parameters	Fixed $V_{reference}$	Vary $V_{reference}$	Fixed Frequency
DAC Duration	Slow	Normal	Normal
Output	Voltage	Current	Voltage
Cost	Low cost	Normal cost	Low Cost
Accuracy	Good	Good	Bad

Conclusions

In conclusion, the DAC are presented in our daily computers, cars, motors ,making our life easy and fast.
This paper has described how digital-to-analogue converters may be constructed in different ways according to different parameters.
In R 2 R ladder DAC the binary weighted principle is implemented, with the repeating 2 R 2 structure.
Although the PWM DAC is simple and low-cost, using it to generate a stable analog voltage output is not a simple, straightforward task.
For MDAC, the conversion is the product of the code created and the alternating reference voltage.

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