10-Bit Potentiometric Digital to Analog Converter with Off-Chip External Voltage Reference

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***Abstract*— This paper presents and demonstrates a 10-bit potentiometric digital to analog converter with an off-chip external voltage reference. A 3.3V of analog voltage and 1.8V of digital voltage is also provided. The D/A converter is revisited with the parameters associated with it. Common errors and nonlinearities related to the DAC are also discussed. Based on string architecture the potentiometric digital to analog converter is presented. Finally the need and application of DACs are explained.**

Keywords—D/A converter, potentiometric, voltage-scaling, DAC, digital-to-analog converter.

I. INTRODUCTION

The world we live in changes rapidly, or we can also say 'continuously'. For numerous applications, we need to measure these continuous variations such as ambient temperature, pressure, humidity, etc. using electronic sensors. These sensors collect analog data and send the digital data converted from an Analog-to-Digital (A/D) Converter to a processing unit. The digital processing unit performs required operations and then spits out streams of digital data in the form of ones and zeros. But human sensory organs do not enjoy these ones and zeros. To convert the data from digital format to analog we require a Digital-to-Analog (D/A) Converter. A digital-to-analog (D/A) converter is a building block that takes a digital data 'D' as an input and generates a voltage 'V_{out}' as output where the V_{out} is directly proportional to D. Because the output voltage is continuous we call it as analog output. This paper presents a 10-bit potentiometric digital to analog converter with an off-chip external voltage reference.

II. PARAMETERS AND ARCHITECTURE OF DIGITAL-TO-ANALOG CONVERTER

The DAC presented here takes 10 bits of digital data as input and produces an analog output. The reference voltage determines the maximum output voltage of the D/A converter. Because the input voltage jumps in steps the corresponding output voltage also does not increase continuously. It can be generalized that a DAC gives the output voltage as

$$V_{out} = F.\ V_{ref} \tag{1}$$

$$V_{out} = [a_{N-1} + \frac{1}{2}a_{N-2} + \dots \dots + \frac{1}{2^{N-2}}a_1 + \frac{1}{2^{N-1}}a_0].\ 2^{N-1}.\ V_{ref} \tag{2}$$

, where V_{out} is the analog output voltage, V_{ref} is the analog reference voltage, F is the fraction defined by input digital word D with width N, and $D = a_{N-1}\, a_{N-2} \dots a_2 a_1 a_0$. The number of input combinations will be equal to 2^N. A 10-bit DAC will have a total of 2^{10} or 1024 total input values. V_{ref} puts a limit on the maximum analog output voltage. The value of F is determined by

$$F = \frac{D}{2^N} \tag{3}$$

Full-scale voltage, V_{FS} is the maximum analog output voltage that can be generated by the DAC.

$$V_{FS} = \frac{2N - 1}{2^N}.V_{ref} \tag{4}$$

The *LSB, least significant bit* is the rightmost bit in the digital input. It is the smallest change that can be done to the analog output voltage. It is denoted as D_0.

$$1\ LSB = \frac{V_{ref}}{2^N}$$

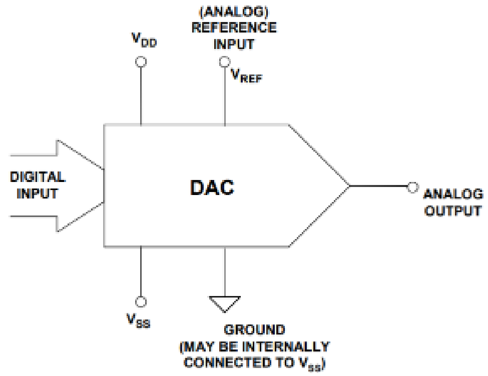

Fig. 1. - showing the basic architecture of Digital to Analog Converter.

Similarly, the *MSB* stands for the most significant bit and it is the leftmost nit of the input. *Resolution or step size* is another crucial term associated with DACs, which is the smallest change that can occur in V_{out} as a result of the change in input D.

Due to component mismatch, noise, non-ideal switches, errors creep into the converters, which make the output offset by a value, non-linear, non-monotonic, etc. A type of error, called *gain error* occurs when the slope of the actual output deviated from the slope of the ideal output in an *Analog Output vs Digital Input Curve*. An *offset error* occurs when there exists a constant offset between the actual output and the ideal output. Two pivotal static characteristics of DAC are, *integral nonlinearity (INL)* which is defined as

INL_n = Output voltage for input digital code – Output value of the reference line through first and last output values (5)

and *differential nonlinearity (DNL)*, which is the difference between the ideal and non-ideal values of the output voltage.

DNL_n = Actual increment in height – Ideal increment in height. (6)

These errors and requirements affect the selection among numerous architectures of the DAC. Broadly there are three types of DAC architectures - current scaling, charge scaling, and voltage scaling.

Despite the limitation in size (a 1 LSB increase in resolution doubles the resistor number), the inherent monotonicity, temperature insensitive, low matching requirements and simplicity of the potentiometer DAC has made it useful for high speed, moderate resolutions (8-10 bits) situations [2]-[3]. It is also sensitive to parasitics which can be reduced by using binary switch arrays which are shown in the fig. 2. The potentiometric DAC employs a string of 2^N resistors to divide V_{ref} into 2^N equal intervals [4]. The CMOS switches are made using transmission gates. Every digital data input bit will be connected directly to the control input of the transmission gate and other control input of transmission gate would be connected through an inverter to the same digital input bit. As the bit changes the switches will select that voltage from the resistors.

For 10-bit DAC, the number of input combinations will be 1024. Our 1024 resistors will divide the voltage and it will be transmitted to V_{out} using an array of switches. If V_{ref} = 5V, then 1 LSB is equal to 4.8828 mV. The percentage accuracy will be 0.0976 and V_{FS} is equal to 4.995V.

One interesting thing to note is that the output of the DAC is not as smooth as the original analog signal. A low pass filter is required to smoothen the signal, which can easily be substituted for the original analog signal.

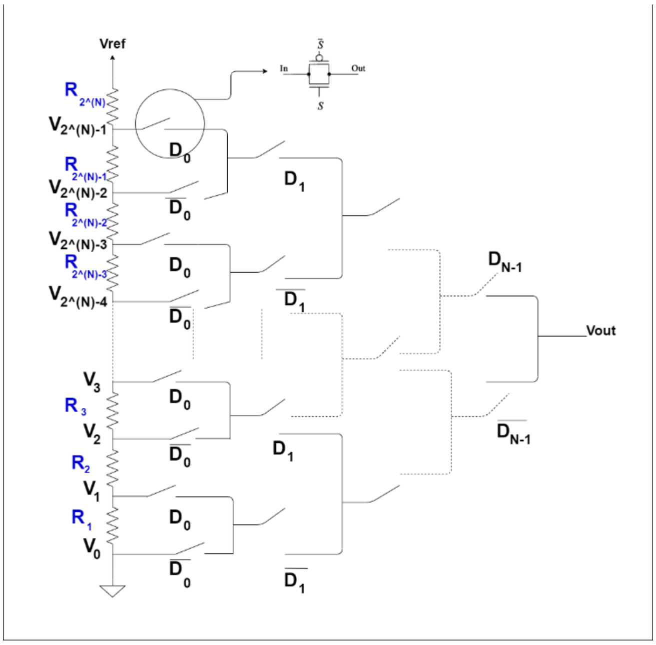

Fig. 2. – showing the N-bit DAC which is implemented for 10-bits.

III. Applications of Digital-to-Analog Converters

In many applications, the systems are critically limited by the performance of analog to digital and digital to analog converters.

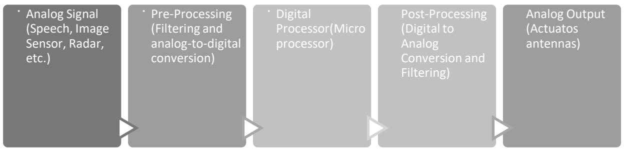

Fig. 3. Showing data acquisition, conversion, and processing stages.

Hence, the requirement of efficient data converters is very much essential in system design.

There are various applications of digital to analog converter deployed in audio systems, image displaying systems, video systems, software-defined radio systems, etc.

A. Audio Systems

The audio signals are stored in digital form and to detect it by human sensory organs they have to be converted into analog signals. So, digital-to-analog converters are used in music player systems to convert digital data streams in analog audio signals which in turn drive the amplifier. This audio DAC is a low-frequency, high-resolution type of D/A converter.

B. Video

Digital video is a representation of a real-world visual scene, sampled spatially and temporally. The size of the video would have been drastically high if codec like H.264, H.265, etc. not have been applied to compress and decompress data. After the generation of digital signals from decoding these signals are fed into digital to analog converters for us to experience the signals.

C. Display Electronics

The digital to analog converters are also used in display electronics where the conversion of digital video data is done to video signals which are connected to the screen drivers for displaying monochromatic or colored images.

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