Digital to Analog and Analog to Digital Conversion

D/A or DAC and A/D or ADC

Real world (lab) is analog

Computer (binary) is digital

Digital to Analog Conversion

D/A Conversion

Computer → DAC

A/D Conversion

Computer → DAC

Digital to Analog Conversion (DAC or D/A)

Digital to Analog conversion involves transforming the computer's binary output in 0's and 1's (1's typically = 5.0 volts) into an analog representation of the binary data.

8 bits

8 bits

D/A conversion can be as simple as a weighted resistor network

4-bit DAC Converter

Resistor values correspond to binary weights of the number D3, D2, D1, D0, i.e. 1/8, 1/4, 1/2, and 1

Using EWB we can model this device
Difficulties:
1. This setup requires a wide range of precision resistors
   A 10 bit DAC needs resistors ranging from $R$ to $R/1024$.
2. The circuit driving the DAC (usually a computer) must supply a wide range of currents for a constant $V_{out}$.

A modification of the weighted resistor DAC is the so-called R-2R LADDER DAC, that uses only 2 different resistances.

An actual R-2R DAC showing input 1 0 1 1

Voltmeter reading is determined by the binary number ABCD and the resistor weights.

MSB = 1/2 of $V_{ref}$
= 1/4 of $V_{ref}$
= 1/8 of $V_{ref}$
LSB = 1/16 of $V_{ref}$

1 0 1 1 = 1/2 (5) + 1/4 (0) + 1/8 (5) + 1/16 (5)
= 3.4 volts

In actual DACs, the converters will drive amplifier circuits in most cases.

As was seen in the Workbench example, the output voltage from a DAC can change by only discrete amounts, corresponding to the level associated with a 1 bit binary change.

For a 8-bit DAC
Smallest step in output voltage is $V/256$
8 bits corresponds to 256 different values
For a 5.0 volt DAC this step size is ~ 19.5 mV
Amplified DAC with bipolar (± V_{out}) output

If one wants only positive or negative output, one can use a BASELINE ADJ. for the Op Amp

Analog-to Digital Conversion (ADC or A/D)

An ideal A/D converter takes an input analog voltage and converts it to a perfectly linear digital representation of the analog signal.

If you are using an 8-bit converter, the binary representation is 8-bit binary number which can take on 2^8 or 256 different values. If your voltage range were 0 - 5 volts, then

```
0 VOLTS 0000 0000
5 VOLTS 1111 1111
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An 8-bit converter can represent a voltage to within one part in 256, or about 0.25%. This corresponds to an inherent uncertainty of ± ½ LSB (least significant bit).

Decimal 128 = 0111 1111

Notice the bits are designated B7 - B0. Bit B7 is the Most Significant Bit while B0 is the Least Significant Bit.
### Types of Analog to Digital Converters

1. **Counter Type**
2. **Integrating or Dual Slope**
3. **Parallel or Flash**
4. **Successive Approximation**

### Counter Type

- **Control Logic**
  - **D A C**
  - **Counter**

- When START is received,
  - control logic initializes the system, (sets counter to 0), and
  - turns on Clock sending regular pulses to the counter.

- As the Clock sends regular pulses to the counter, the counter outputs a digital signal to the Digital-to-Analog converter

- As the counter counts, its output to the D A C generates a staircase ramp to the comparator.

- As the ramp voltage increases to the comparator, it rises closer and closer to $V_{in}$ at which point the comparator shifts states.
When the ramp voltage exceeds $V_{in}$, the comparator output shifts which signals the control logic to turn off the clock.

With the clock off, the counter reading is proportional to $V_{in}$.

Note that the conversion time depends on the size of the input signal.

With a counter type A/D, if the signal is varying rapidly, the counter must count up and reset before each cycle can begin, making it difficult to follow the signal.

Once the digital output has been read by the associated circuitry, a new start signal is sent, repeating the cycle.

Tracking ADC - similar to the counter type except it uses an up/down counter and can track a varying signal more quickly.

When conversion is initialized, the switch is connected to $V_{in}$, which is applied to the op amp integrator. The integrator output (>0) is applied to the comparator.

Integrating or Dual Slope A/D

When conversion is initialized, the switch is connected to $-V_{ref}$, which is applied to the op amp integrator. The integrator output (>0) is applied to the comparator.
As conversion is initiated, the control logic enables the clock which then sends pulses to the counter until the counter fills (9999).

As the counter resets (9999 → 0000), an overflow signal is sent to the control logic. This activates the input switch from $V_{in}$ to $-V_{ref}$, applying a negative reference voltage to the integrator.

The negative reference voltage removes the charge stored in the integrator until the charge becomes zero.

At this point, the comparator switches states producing a signal that disables the clock and freezes the counter reading.

The total number of counts on the counter (determined by the time it took the fixed voltage $V_{ref}$ to cancel $V_{in}$) is proportional to the input voltage, and thus is a measure of the unknown input voltage.

Since this A/D integrates the input as part of the measuring process, any random noise present in the signal will tend to integrate to zero, resulting in a reduction in noise.

These type of A/Ds are used in almost all digital meters. Such meters usually are not used to read rapidly changing values in the lab. Consequently the major disadvantage of such converters (very low speeds) is not a problem when the readout update rate is only a few times per second.

The operation of this A/D requires 2 voltage slopes, hence the common name DUAL-SLOPE.

Flash Converters

If very high speed conversions are needed, e.g. video conversions, the most commonly used converter is a Flash Converter.

While such converters are extremely fast, they are also very costly compared to other types.
Parallel or Flash Converters

The resistor network is a precision voltage divider, dividing \( V_{\text{ref}} \) (8 volts in the sample) into equal voltage increments (1.0 volts here) to one input of the comparator. The other comparator input is the input voltage.

Each comparator switches immediately when \( V_{\text{in}} \) exceeds \( V_{\text{ref}} \). Comparators whose input does not exceed \( V_{\text{ref}} \) do not switch.

A decoder circuit (a 74148 8-to-3 priority decoder here) converts the comparator outputs to a useful output (here binary).

The speed of the converter is limited only by the speeds of the comparators and the logic network. Speeds in excess of 20 to 30 MHz are common, and speeds > 100 MHz are available ($$$$$$).

The cost stems from the circuit complexity since the number of comparators and resistors required increases rapidly. The 3-bit example required 7 converters, 6-bits would require 63, while an 8-bits converter would need 256 comparators and equivalent precision resistors.

While integrating or dual-slope A/Ds are widely used in digital instruments such as DVMs, the most common A/D used in the laboratory environment is the successive approximation.

Successive approximation converters are reasonably priced for large bit values, i.e. 10, 12 and even 16 bit converters can be obtained for well under $100. Their conversion times, typically ~10-20 \( \mu s \), are adequate for most laboratory functions.

At initialization, all bits from the SAR are set to zero, and conversion begins by taking STRT line low.

First the logic in the SAR sets the MSB bit equal to 1 (+5 V). Remember that a 1 in bit 7 will be half of full scale.
The output of the SAR feeds the D/A converter producing an output compared to the analog input voltage. If the D/A output is < Vin then the MSB is left at 1 and the next bit is then tested.

If the D/A output is > Vin then the MSB is set to 0 and the next bit is set equal to 1.

Successive bits are set and tested by comparing the DAC output to the input \( V_{in} \) in an 8 step process (for an 8-bit converter) that results in a valid 8-bit binary output that represents the input voltage.

Note that the successive approximation process takes a fixed time - 8 clock cycles for the 8-bit example.

For greater accuracy, one must use a higher bit converter, i.e., 10-bit, 12-bit, etc. However, the depth of the search and the time required increases with the bit count.
Workbench Models

flash adc(works).ewb

dac_dig.ewb

adc-dac2.ewb