Mechatronics Engineering

ADC

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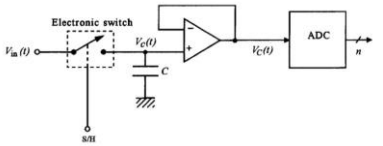
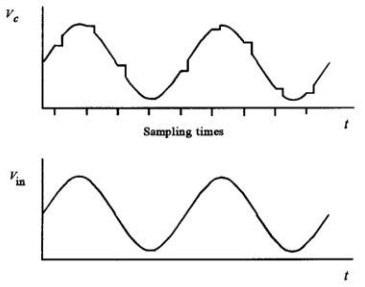
Sample and Hold

- Obviously, if the input is changing while the ADC performs the conversion process , errors will occur.
- What is needed is simply that the signal not change during the conversion process.
- Therefore, the answer is to hold the value constant during that process, which is accomplished with a sample-and-hold (S/H) circuit.
- The basic concept of the sample and hold circuit is shown in Figure below. Where the S/H is connected to the input of an ADC.
- When the electronic switch is closed, the capacitor voltage will track the input voltage, $V_c(t) = V_{in}(t)$.
- At some time, t_s, when conversion of the input voltage is desired, the electronic switch is opened, isolating the capacitor from the input.
- Thus the capacitor will hold (stay charged) to the voltage when the switch opened, $V_c = V_{in}(t_s)$.

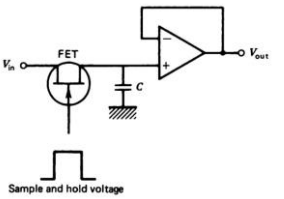


The basic concept of a sample-and-hold circuit for use with the ADC.

- The voltage follower allows this voltage to be impressed upon the ADC input, but the capacitor does not discharge because of the very high input impedance of the follower.
- The start-convert is then issued, and the conversion proceeds with the input voltage remaining constant.
- When the conversion is complete, the electronic switch is reclosed, and tracking continues until another conversion is needed.
- Figure below shows how $V_{in}(t)$ and $V_c(t)$ would appear during a sample collection sequence of a sinusoidal signal.



The sampled signal is literally "held" during the ADC conversion process.



A S/H often uses a FET as an electronic switch.

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Analog/Digital Conversion

Digitization

- Sampling (Time Axis)
- Quantization (Amplitude Axis)

Sampling

The process of defining the instantaneous points at which the data are to be observed.

Quantization

The process of converting the analog data values at the sampling points into digital form.

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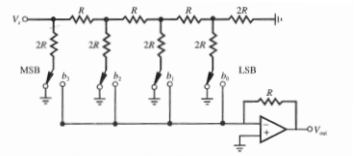
DAC Structure

- Generally speaking a DAC is used as a black box, and no knowledge of the internal workings is required.
- There is some value, however, in briefly showing how such conversion can be implemented.
- The most common variety uses a *resistive ladder network* to provide the transfer function.
- This is shown in Fig. below for the case of a 4-bit converter. With the R-2R choice of resistors, and through network analysis the output voltage is given by Eqs. (1) or (2). The switches are analog electronic switches.
- The digital input to the DAC is a 4-bit binary number represented by bits b_0, b_1, b_2, and b_3, where b_0 is the least significant bit.
- Each bit in the circuit controls a switch between ground and the inverting input of the op amp.
- To understand how the analog output voltage V_{out} is related to the input binary number, we can analyze the four different input combinations 0001, 0010, 0100, and 1000 and apply the principle of superposition for an arbitrary 4-bit binary number.



4-bit resistor ladder D/A converter.

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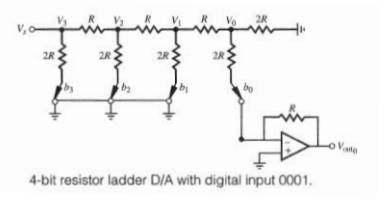
- If the binary number is 0001, the b_0 switch is connected to the op amp, and the other bit switches are grounded. The resulting circuit is as shown.
- Since, the noninverting input of the op amp is grounded, the inverting input is at a virtual ground.
- The resistance between node V_0 and ground is R, which is the parallel combination of two $2R$ values. Therefore, V_0 is the result of voltage division of V_1 across two series resistors of equal value R:

$V_0 = \frac{1}{2}V_1$ Similarly, we can show that

$V_1 = \frac{1}{2}V_2$ and $V_2 = \frac{1}{2}V_3$

Therefore, $V_0 = \frac{1}{8}V_3 = \frac{1}{8}V_s$



4-bit resistor ladder D/A with digital input 0001.

V_0 is the input to the inverting amplifier circuit, which has a gain of

$-\frac{R}{2R} = -\frac{1}{2}$

Therefore, the analog output voltage corresponding to the binary input 0001 is

$V_{\text{out}_0} = -\frac{1}{16}V_s$

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Similarly, we can show that, for the input 0010, $V_{out_1} = -\frac{1}{8}V_s$

and for the input 0100, $V_{out_2} = -\frac{1}{4}V_s$

and for the input 1000, $V_{out_3} = -\frac{1}{2}V_s$

The output for any combination of bits comprising the input binary number can now be found using the principle of superposition :

$V_{out} = b_3 V_{out_3} + b_2 V_{out_2} + b_1 V_{out_1} + b_0 V_{out_0}$

If V_s is $10V$, the output ranges from 0V to $(-15/16)10$V for the 4-bit binary input, which has 16 values ranging from $0000\,(0)$ to $1111\,(15)$. A negative reference voltage V_s can be used to produce a positive output voltage range.

Either case yields a unipolar output, which is either positive or negative but not both. A **bipolar** output, which ranges over negative and positive values, can be produced by replacing all ground references in the circuit with a reference voltage whose sign is opposite to V_s.

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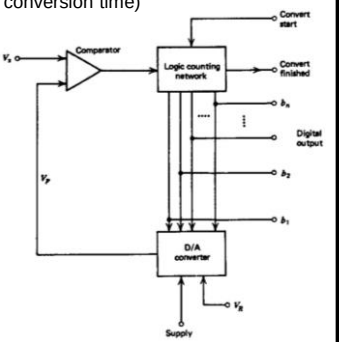
ADC Structure
Successive Approximation

- Most ADCs are available in the form of IC assemblies that can be used as a black box in applications.
- To fully appreciate the characteristics of these devices, however, it is valuable to examine the standard techniques employed to perform the conversions.
- There are two methods in use that represent very different approaches to the conversion problem.
- The successive approximation ADC and Dual Slope Ramp ADC (long conversion time)
- The Successive Approximation ADC employs a feedback system to perform the conversion.
- Essentially, a comparator is used to compare the input voltage, V_x, to a feedback voltage, V_F, that comes from a DAC.
- The comparator output signal drives a logic network that steps the digital output (and hence DAC input) until the comparator indicates the two signals are the same within the resolution of the converter.
- The logic circuitry is such that it successively sets and tests each bit, starting with the most significant bit of the word.



successive approximation converter

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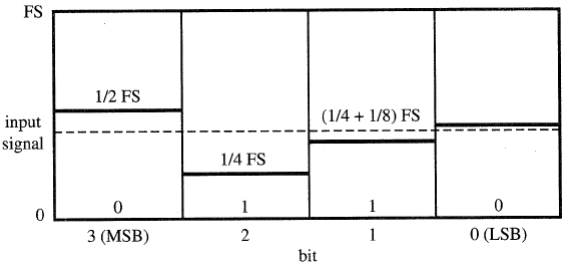
- We start with all bits zero. Thus, the first operation will be to set $b_1 = 1$, and test $V_F = V_R 2^{-1}$ against V_x through the comparator.
- If V_x is greater, then b_1 will be 1, b_2 is set to 1, and a test is made of V_x versus $V_V = V_R (2^{-1} + 2^{-2})$, and so on.
- If V_x is less than $V_R 2^{-1}$, then b_1 is reset to zero, b_2 is set to 1, and a test is made of V_x versus $V_R 2^{-2}$.
- This process is repeated to the least significant bit of the word.
- The conversion time of successive approximation-type ADCs is on the order of 1 to 5 μs per bit.



4-bit successive approximation A/D conversion for the digital result: 0110

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Example

Find the successive approximation ADC output for a 4-bit converter to a 3.217-V input if the reference is 5 V.

Solution :

Following the procedure outlined, we have the following operations :

Let $V_x = 3.217$; Then

(1) Set $b_1 = 1$ $\quad V_F = 5\left(2^{-1}\right) = 2.5$ V

$V_x > 2.5$ $\quad$ leave $b_1 = 1$

(2) Set $b_2 = 1$ $\quad V_F = 2.5 + 5\left(2^{-2}\right) = 3.75$

$V_x < 3.75$ $\quad$ reset $b_2 = 0$

(3) Set $b_3 = 1$ $\quad V_F = 2.5 + 5\left(2^{-3}\right) = 3.125$

$V_x > 3.125$ $\quad$ leave $b_3 = 1$

(4) Set $b_4 = 1$ $\quad V_F = 3.125 + 5\left(2^{-4}\right)$

$V_x < 3.4375$ $\quad$ leave $b_4 = 0$

By this procedure, we find the output is a binary word of 1010_2.

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Example

A measurement of temperature using a sensor that outputs 6.5 mV/°C must measure to 100°C. A 6-bit ADC with a 10-V reference is used. (a) Develop a circuit to interface the sensor and the ADC. (b) Find the temperature resolution

Solution:

To measure to 100°C means the sensor output at 100°C will be

$(6.5\,\text{mV/°C})(100°\text{C}) = 0.65\,\text{V}$

a. The interface circuit must provide a gain so that at 100°C the ADC output is 111111. The input voltage that will provide this output is found from

$$V_x = V_R\left(a_1 2^{-1} + a_2 2^{-2} + \cdots + a_6 2^{-6}\right)$$

$$V_x = 10\left(\frac{1}{2} + \frac{1}{4} + \cdots + \frac{1}{64}\right) = 9.84375\text{V}$$

Thus, the required gain must provide this voltage when the temperature is 100°C.

$$\text{gain} = \frac{9.84375}{0.65} = 15.14$$

The op amp circuit of Figure will provide this gain.

b. The temperature resolution can be found by working backward from the least significant bit (LSB) voltage change of the ADC:

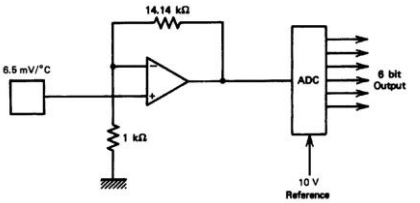
$$\Delta V = V_R 2^{-n} = (10)(2^{-6}) = 0.15625\text{V}$$

Working back through the amplifier, this corresponds to a sensor change of

$$\Delta V_T = \frac{0.15625}{15.14} = 0.01032\ \text{V}$$

or the temperature of

$$\Delta T = \frac{0.01032\text{V}}{0.0065\text{V/°C}} = 1.59°\text{C}$$



Analog circuit for Example

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