Session 10 Lecture Notes

Announcements

1. Understanding Data Converters Application Report from Texas Instruments
2. To Hand In:
   (a) Homework 5 is due on 2020-02-21

Digital-to-Analog Converters

For a typical **unipolar** D/A converter with a digital input D of N bits:

- The number of distinct output voltages is 2^N
- The **output voltage**: $V_{OUT} = \frac{D}{2^N} V_{REF}$
- The **voltage resolution** of the converter is the voltage equivalent to one LSB
- The **resolution** is $V_{LSB} = \frac{V_{REF}}{2^N}$
- The **maximum output** is $V_{MAX} = \frac{2^N - 1}{2^N} \cdot V_{REF}$
- Other important specifications include linearity and settling time

A unipolar D/A converter only produces positive output voltages, which is fine for many applications. A bipolar D/A converter is much more complicated and requires a negative supply voltage, so they are less common.

Note that we are blithely assuming that V_{REF} is a perfect voltage source. In reality, the effective resolution of a D/A converter is also limited by the accuracy of V_{REF} as well as the level of noise present on this voltage. If you just use some supply voltage, like V_{DD}, as V_{REF} then you will be lucky to get 5 or 6 solid bits of resolution. Plan to spend a few dollars for a precision voltage reference if you want better data than that.

Digital-to-Analog Converters

For an **R2R** D/A converter…

- Total number of resistors is $\approx 2N$
- Total number of switches is N
- The ratio of largest to smallest resistor is $2 : 1$
- Possible to use $\approx 3N$ **identical** resistors
- The necessary resistor **matching accuracy** is $\approx \frac{1}{2^N}$
- Resistor matching limits resolution to about 14-16 bits

The R2R ladder circuit is popular because it uses a reasonable number of resistors and switches. If we make the 2R resistor from two R resistors in series then all of the resistors can have the same value and it is again a matter of making them all the same rather than trying to make any particular resistance value.

Analog-to-Digital Converters

- Other terms for an analog-to-digital converter: A/D, ADC, digitizer, quantizer
- The maximum input voltage (V_{MAX}), or full-scale range (FSR) is

$$V_{MAX} = FSR = \frac{2^N - 1}{2^N} \times V_{REF}$$

- The digital integer output, D is defined as

$$D = \frac{V_{IN}}{V_{REF}} \times 2^N$$

- The resolution (value of one LSB) is

$$V_{LSB} = \frac{V_{REF}}{2^N}$$

- Note that V_{REF} may be fixed by the ADC manufacturer
- The **quantization error** is the difference between the actual analog input value and the digitized output for an **ideal** ADC

Oversampling and Averaging

Random errors in the ADC output can be reduced by **oversampling** and **averaging**.

Averaging **does not** remove systematic errors such as **gain error** and **offset error**.

Beware of **numerical errors** when averaging!

CircuitPython uses 32-bit integers by default, which have a maximum positive value of 2 147 483 647. If you add so many sample values together that you could exceed this value then your average will be horribly corrupted.

CircuitPython uses single-precision floating-point values by default. These values have only about seven significant digits. If you add sample values together and get a sum that needs more than seven significant digits to represent exactly then you will have roundoff error in your results.

Analog Input, Feather M0 Express

Characteristics of the SAM21D ADC

- 8-bit, 10-bit, or 12-bit resolution
- Up to 350ksps (samples per second)

Characteristics of CircuitPython on Feather M0 Express

```
from analogio import AnalogIn
my_analog_in = AnalogIn(board.A1) // A0 through A5 available
print(my_analog_in.value)
my_input_voltage = my_analog_in.value * 3.3 / 65536
```

- The ADC is configured for 12-bit resolution
- The `value` method returns the ADC output left-justified in a 16-bit integer

