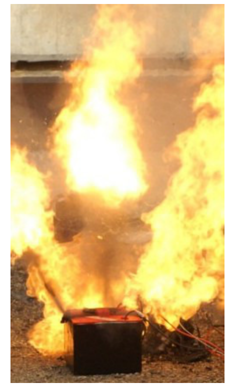
1a. Battery-pack sensing: Voltage

- We now begin to look at the five requirement areas of a BMS design in more detail
- This week, our focus is on requirement 1, *sensing and high-voltage control*
- We start by considering how we measure cell voltage
- All cell voltages are measured in a lithium-ion pack
  - Indicator of relative balance of cells
  - Input to most SOC and SOH estimation algorithms
  - Safety: overcharging a lithium-ion cell can lead to "thermal runaway," so we cannot skip measuring any voltages



Some methods for analog-to-digital conversion

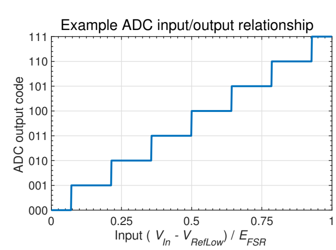
- At the most basic level, voltage is measured using an analog-to-digital converter (ADC, A/D, A–D, A2D, or A-to-D)
- There are several common ADC architectures; for example,
  - A direct-conversion or flash ADC uses a bank of comparators and fixed reference voltages, outputs code of closest reference (fast, expensive)
  - Successive approximation compares input to output from DAC and uses feedback to modify DAC signal, resolving input to desired accuracy (slow, inexpensive)
  - Delta-sigma ($\Delta\Sigma$) uses oversampled 1-bit flash ADC to encode difference (Δ) between approximation and input, sums (Σ) differences and filters to give final high-resolution result at desired slower sample rate (very popular)
- All are generally implemented in ICs due to need for precisely matched components

Resolution of an ADC

- The resolution of an ADC is the smallest change in the input signal that can be measured; it is also the step size between consecutive ADC output codes
- An ADC having an M-bit output has 2^M output codes
- If these are distributed evenly over an input range from V_{RefLow} to $V_{RefLow} + E_{FSR}$, the resolution is $E_{FSR}/2^M$
- For example, if an ADC has input range of 0 V to 5 V and has 16 bits of precision, the resolution Q is

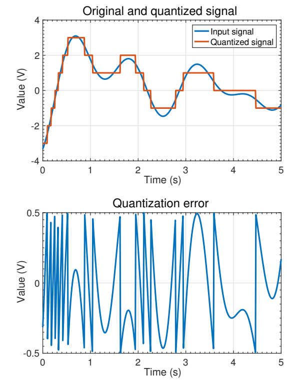
$$Q = (5\,\text{V} - 0\,\text{V})\,/2^{16} = 76\,\mu\text{V}$$

- This is also often termed the "LSB voltage"



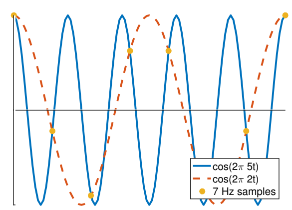
Accuracy of an ADC

- The accuracy of an ADC has to do with the absolute difference between the reported value and the true value: difference may be due to several sources
  - Quantization error (unmeasurable value between $\pm Q/2$)
  - Offset error (constant difference between ideal and measured value over whole measurement range)
  - Gain error (difference between slope of ideal and measured value over whole measurement range, expressed as %)
  - Nonlinear error (deviation between actual and ideal step widths, expressed as ADC counts)



Other ADC considerations

- Temperature:
  - Offset/gain/nonlinear errors are function of temperature
- Timing jitter:
  - Absolute time between samples is not exactly constant
- Aliasing:
  - By Nyquist sampling theorem, sample rate should be at least twice the highest frequency in the input signal
  - Otherwise, high-frequency inputs will be aliased as low-frequency signals in the sampled signal

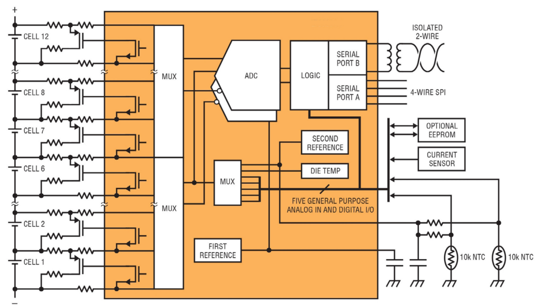


Chipsets

- Special chipsets are made to aid high-voltage BMS design
  - Low-cost “dumb” measurement chips used in modules, proximate to cells; high-cost computational processing in distant master unit
  - Special chips implement difficult task of highly accurate A2D voltage sensing with high common-mode rejection and fast response in high-EMI, high-heat, high-vibration environments
  - Can often be placed in parallel for redundant fault-tolerant designs.
- Multiple vendors make chipsets (e.g., Analog Devices, Maxim, Texas Instruments)

Example chipset: LTC6811

- We consider a specific example (LTC6811) designed by Analog Devices (formerly Linear Technology)
- Monitors up to 12 cells in series in a module, 100s of cells in series in pack
- Has built-in isolated communications between daisy-chained parts
- Supports internal or external cell-equalization circuitry
- Powered by module itself, or externally
- Measures up to five temperatures (more with some external circuitry)



Selecting a chipset

- Points to be considered in a design:
  - How many cells can each IC monitor?
  - How many cells total can be monitored?
  - Does it support passive/active balancing?
  - What is the measurement accuracy?
  - How many temperature measurements can be made?
  - How many wires to communicate from IC to IC?
  - What is chipset availability and cost, per cell?

Summary

- All battery cell voltages in a lithium-ion battery pack must be monitored continuously
- This is done using an analog-to-digital converter, generally built into an IC
- Resolution and accuracy are A2D features that must be considered in a design
- Special chipsets are available from several silicon vendors to help monitor high-capacity battery packs
- We discussed some criteria to consider when selecting a chipset

Credits

Credits for photos in this lesson

- Lithium-ion battery fire on slide 1: By Daniel Steger (own work) [CC BY-SA 3.0 (`http://creativecommons.org/licenses/by-sa/3.0`)], `http://openphoto.net/gallery/image/view/18613`
- LTC6811 block diagram on slide 7: from `http://www.linear.com/docs/46925`, "Maximizing Cell Monitoring Accuracy and Data Integrity in Energy Storage Battery Management Systems"