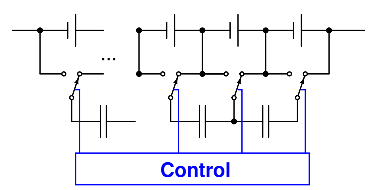
Active balancing

- Last week, you learned about the need for balancing, and some balancing criteria and strategies
- You also learned some passive-balancing circuits
- This week, you will also learn about active balancing
- Active balancing circuits break down into three general categories:
  - Move charge via switched capacitors
  - Move energy via transformer/inductor designs
  - Use dc-dc converter techniques to discharge high cells and charge low cells
- In this lesson, you will learn about switched-capacitor-based designs

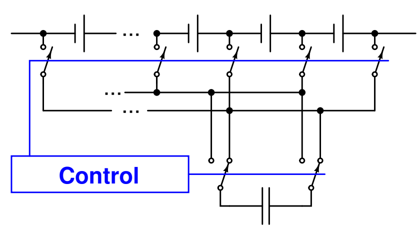
Active: Multiple switched capacitors

- In circuit to right, there is one fewer capacitor than there are battery-pack cells
- Single-pole-double-throw (transistor circuit) switches repeatedly back and forth (no intelligence)
- Consider two neighboring cells:
  - High-voltage cell charges capacitor to its voltage, then low-voltage cell discharges capacitor to its voltage: charge moves to equalize cell voltages
- Over the course of time, entire pack is equalized
  - But, charge takes a long time to propagate from one end of the pack to the other



Active: One switched capacitor

- An alternate design uses a single switched capacitor, with intelligent control
- This allows direct movement of charge from a high-voltage to a low-voltage cell
- A serious drawback of all capacitor-based designs is that they rely on a voltage difference between cells in order to work
- Most Li-ion chemistries have very little voltage variation between cells even if SOC varies a lot
- We explore this idea on the next slide



Rate of change of SOC

- Maximum energy transferred is $E = \frac{1}{2}C(v_{\text{high}}^2 - v_{\text{low}}^2)$
- Energy can be related to change in SOC: $E \approx (\Delta z)Q\,v_{\text{nom}}$
- Suppose that $v_{\text{nom}} \approx \frac{v_{\text{high}}+v_{\text{low}}}{2}$
- Then, equating the two energies gives

$$(\Delta z)Q\frac{v_{\text{high}} + v_{\text{low}}}{2} \approx \frac{1}{2}C(v_{\text{high}} + v_{\text{low}})(v_{\text{high}} - v_{\text{low}})$$

$$\Delta z \approx \frac{C}{Q}\Delta v,$$

where Q must be measured in coulombs for the units to agree

Example of rate of charge transfer

- Consider a 10 Ah cell (36 000 C): would like to compute Δz when $\Delta v = 0.1$ V
- Can select any capacitance value, but note that high-valued capacitors have high resistance so will charge slowly (not accounted for in our simple approximations)
- Even if we select a (ridiculously) large value of $C = 1$ F, we get

$$\Delta z \approx \frac{1}{36\,000} \times 0.1 \approx 3 \times 10^{-6}$$

- At this rate, it will take forever to equalize!
- Capacitor designs okay for EV, where Δv can be fairly large in unbalanced packs
- Not good for HEV, as cells are operated in smaller SOC window, and Δv very small

Summary

- Capacitor circuits can be used to move charge from high-voltage cell(s) to low-voltage cell(s)
- Less wasteful than passive balancing, since most energy conserved (some still lost through parasitic resistance as heat)
- But, designs in this lesson balance slowly as rate depends on voltage differences, which can be very small in Li-ion battery packs even if cells are far from balanced
- Other capacitor-based designs can charge single capacitor from overall stack, then discharged into a low-voltage cell
  - Can be faster as Δv is voltage difference between stack and single cell's voltage, but requires computer control so capacitor voltage rating not exceeded
- Next lesson, you will learn about inductor-based methods, which can be faster