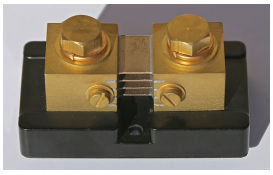
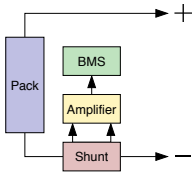
1c. Battery-pack sensing: Current

- Battery pack electrical current measurements are required:
  - To monitor battery-pack safety
  - To log abuse conditions
  - By most state-of-charge and state-of-health algorithms
- We cannot measure electrical current directly—must convert to voltage and measure via A2D
- There are two basic methods to do so:
  - Using a resistive shunt, and
  - Using a Hall-effect mechanism

Shunt current sensor

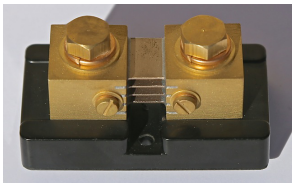
- Shunt sensor is low-value (*e.g.*, 0.1 mΩ) high-precision resistor in series with battery pack, usually at low-voltage end
- Current computed by measuring voltage drop: $I = V_{\text{shunt}}/R_{\text{shunt}}$
- Since the shunt resistance must be small (to avoid large power losses due to $i^2 R_{\text{shunt}}$ heating), the voltage drop across the shunt will be small as well
- So, the voltage is usually amplified before sensing and the calculation for current is adjusted accordingly





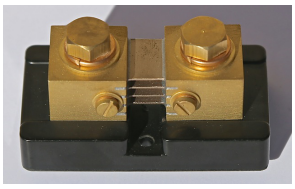
Shunt details

- Examining the device in more detail, note that there are four connection terminals
  - One large terminal on the top is connected to the negative terminal of the battery stack, the other to the output negative terminal of the battery pack
  - Pack current passes through parallel plates that form the calibrated resistance in the center of the shunt
  - The resistance between the two smaller screw terminals is calibrated, and the sensing leads are connected to these smaller terminals



Kelvin four-wire connection

- Connecting using these four terminals is called a Kelvin connection and enables four-wire voltage measurement
- Essentially no current is drawn by the A2D, so there is negligible voltage drop across resistance of smaller terminals: current can be calculated as stated earlier
- However, if one were to (mistakenly) connect the voltage-sensing wires to the larger terminals, the voltage drop of the battery-pack current passing through the uncalibrated resistance of the terminals would significantly degrade the accuracy of the current calculation

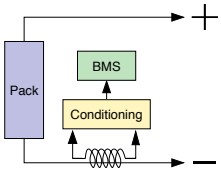


Shunt current-sensor comments

- Some comments on current-sensing shunts:
  - Power and sense connections must be made separately
  - Shunts have no offset at zero current, so are good to avoid drift in coulomb counting (but, offset might still be introduced by amplifier or A2D)
  - Current shunts are not electrically isolated from the pack: if BMS must be isolated from pack, extra circuitry is required
  - Resistance of current shunt changes with temperature, so temperature must be measured and resistance calibrated
  - Heat generated via i^2R shunt losses must be dissipated
  - Amplification of shunt signal is necessary—wiring must be shielded from EMI

Hall-effect current sensing

- If a coil is wrapped around a primary current-carrying conductor, the electromagnetic field produced by the conductor induces a secondary current in the coil
- Hall-effect sensors measure this induced current to infer the primary current
- Main battery-pack current-carrying wire passes through the oval opening in the center of the sensor—no direct electrical connection is made between the sensor and the high-voltage battery pack



Hall-effect current-sensor comments

- Some comments on Hall-effect sensors:
  - Hall-effect sensors are electrically isolated from pack current, so no special isolation circuitry is needed
  - Feedback circuitry is needed to guard against sensor magnetic hysteresis (sometimes packaged with sensor)
  - Even so, Hall-effect sensors suffer from offset at zero current, which changes with temperature
    - Even if “zeroed” at room temperature, will report incorrect current as they change temperature
    - As the bias plays havoc with a number of BMS algorithms, some kind of compensation is necessary

Summary

- Battery pack electrical current must be measured to monitor safety, log abuse, and inform SOC and SOH algorithms
- Two methods may be used: either current shunt or Hall-effect sensor
- Both methods have advantages and disadvantages and both are in common use in BMS today