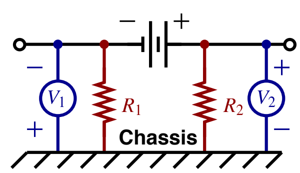
1e. Isolation sensing

- Isolation sensing detects presence of a ground fault
- Primary concern is safety: Is it safe to touch a battery terminal and chassis ground at the same time?
- Battery "should" be completely isolated from chassis ground, so "should" be no problem
- FMVSS says isolation is sufficient if less than 2 mA of current will flow when connecting chassis ground to either the positive or negative terminal of the battery pack via a direct short

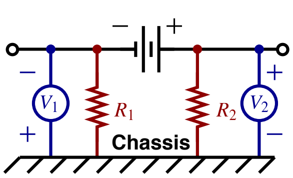
Setting up problem

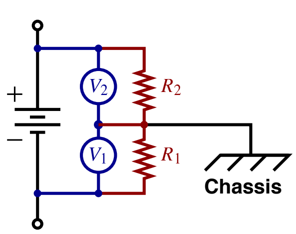
- In the diagram, paths between battery and chassis ground are drawn as red (ideally infinite) resistors
- The "isolation resistance" R_i is the lesser of R_1 and R_2. So, R_i must be greater than $V_b/0.002 = 500V_b$
- For the BMS to sense whether the pack is sufficiently isolated from the chassis, it must somehow measure R_i



- To do so, we measure V_1 and V_2 using a high-impedance A2D, $\geq$ 10 MΩ
  - This breaks strict isolation, but not enough to worry about
  - Note polarity of voltmeters—both V_1 and V_2 are positive

Redrawing circuit to clarify analysis

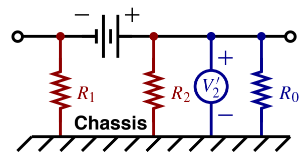




- If we redraw the circuit, it becomes more clear that R_1 and R_2 form a voltage divider
- We want to find the smaller of the two resistances
  - In a voltage divider, the smaller voltage corresponds to the smaller resistor
  - So if $V_1 < V_2$ find R_1, else find R_2
- Note also that $I_1 = I_2$ so $V_1/R_1 = V_2/R_2$
  - We'll use this identity as we solve the problem

Fault on low side: Find R_1

- If the fault is on the low side, we want to solve for R_1
- We insert a known large resistance R_0 between battery and chassis ground, via a transistor switch, as shown
- This again breaks strict isolation, but not enough to worry about if R_0 is "big enough" (*i.e.*, $\gg 500V_b$)
- We measure V_2'. Note that by KCL, $\frac{V_b - V_2'}{R_1} = \frac{V_2'}{R_2} + \frac{V_2'}{R_0}$
- Substitute $V_b = V_1 + V_2$ and $R_2 = R_1(V_2/V_1)$,

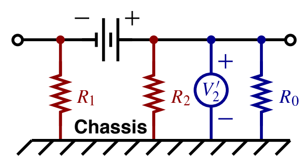


$$\frac{(V_1 + V_2) - V_2'}{R_1} = \frac{V_2'}{R_2} + \frac{V_2'}{R_0}$$
$$= \frac{V_2'(V_1/V_2)}{R_1} + \frac{V_2'}{R_0}$$

Fault on low side: Find R_1 (continued)

- Last slide, we concluded

$$\frac{(V_1 + V_2) - V_2'}{R_1} = \frac{V_2'(V_1/V_2)}{R_1} + \frac{V_2'}{R_0}$$



- Now, combine terms that include R_1

$$\frac{(V_1 + V_2) - V_2' - V_2'(V_1/V_2)}{R_1} = \frac{V_2'}{R_0}$$

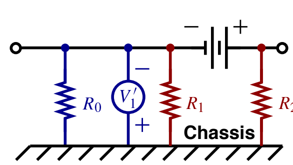
- Rearranging,

$$R_1 = \frac{R_0}{V_2'}(V_1 + V_2 - V_2' - V_2'(V_1/V_2)) = \frac{R_0}{V_2'}\left(1 + \frac{V_1}{V_2}\right)(V_2 - V_2')$$

- Isolation is deemed sufficient if $R_i > V_b/0.002$ or $R_1 > 500V_b$

Fault on high side: Find R_2

- Procedure is similar if the initial voltage measurements $V_1 > V_2$ except that now we want to find R_2
- We insert a known large resistance R_0 between battery and chassis ground, via a transistor switch, as shown
- We now measure V_1'. Then, by KCL,



$$\frac{V_b - V_1'}{R_2} = \frac{V_1'}{R_1} + \frac{V_1'}{R_0}$$

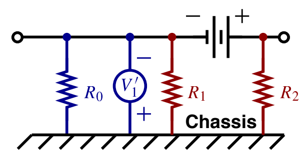
- Substitute $V_b = V_1 + V_2$ and $R_1 = R_2(V_1/V_2)$

$$\frac{V_1 + V_2 - V_1'}{R_2} = \frac{V_1'(V_2/V_1)}{R_2} + \frac{V_1'}{R_0}$$

Fault on high side: Find R_2 (continued)

- Last slide, we concluded

$$\frac{V_1 + V_2 - V_1'}{R_2} = \frac{V_1'(V_2/V_1)}{R_2} + \frac{V_1'}{R_0}$$



- Now, combine terms that include R_2

$$\frac{V_1 + V_2 - V_1' - V_1'(V_2/V_1)}{R_2} = \frac{V_1'}{R_0}$$

- Rearranging,

$$R_2 = \frac{R_0}{V_1'}(V_1 + V_2 - V_1' - V_1'(V_2/V_1)) = \frac{R_0}{V_1'}\left(1 + \frac{V_2}{V_1}\right)(V_1 - V_1')$$

- Isolation is deemed sufficient if $R_i > V_b/0.002$ or $R_2 > 500V_b$

Summary

- In a vehicle application, we must maintain isolation between high-voltage battery pack and chassis of the vehicle
- Isolation is deemed sufficient if less than 2 mA of current will flow if a direct short is placed between one terminal of the battery pack and the chassis
- We explored the FMVSS procedure for determining the isolation resistance R_i of the battery pack
- Isolation is sufficient if $R_i > 500V_b$

Credits

Credits for photos in this lesson

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