# A Broken Line Detection Circuit for Multi-cell Li-ion Battery Module[1]

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***Abstract*—This paper presents a novel broken line detection circuit for multi-cell Li-ion Battery modules. The broken line detection technique detects test lines between the battery pack and any following circuit, e.g., BMS (battery management system). The core of the broken line detection circuit consists of an RC filter, a Brokenline Detection Block, and a bias voltage source. A system-level experiment verifies that the proposed circuit can reliably detect any disconnection of Li-ion battery pack and the following circuit to ensure the safety of the system.**

## I. Introduction

Recently, many Li-ion battery packs are used in high-voltage and high-spindle equipments or systems such as electric vehicles (EV) [1], UPS, and high-power electric tools [2]. The existing Li-ion battery is usually equiped with overcharge, and over-discharge detection ICs to ensure the safety of the battery cell when multiple cells are connected in series. However, the existing protection IC cannot check the disconnection, namely open circuit, for each battery cell. The undetected open circuit in a battery pack might result in wrong readings of the battery state, and even safety issues. Therefore, to constantly and accurately detect perfect connection of the battery detection lines, a battery disconnection detection circuit is proposed to resolved the mentioned problems [3][4][5]. Fig. 1 shows a typical battery-powered system in an EV, where Broken Line Detector is positioned between the Battery Module and BMS. It is composed of an RC filter, a bias voltage source, a current source, PMOS and NMOS switches. As soon as a detection line is opened, the corresponding MOS switch will be turned on to pull up a warning flag signal $(\mathrm{Vouti}_{(\mathrm{i}=1,2,3)})$ from low to high, to the following circuit such that the BMS can take corresponding actions.

## II. Broken Line Detector (BLD) Design

Fig. 2 shows the operation flow of the Broken Line Detector (BLD). The illustrative example is equipped with 4 Li-ion battery cells, the RC filter and Brokenline Detection Block, as is shown in Fig. 3. To detect open or short of each lines, every battery is coupled to a corresponding MOS switch.

1. This research was partially supported by Ministry of Science and Technology under grant MOST 107-2218-E-110-004-.

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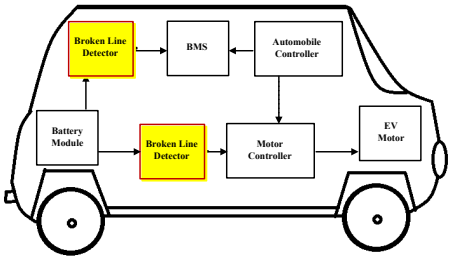


Fig. 1. A typical power system in an EV with Broken Line Detectors.

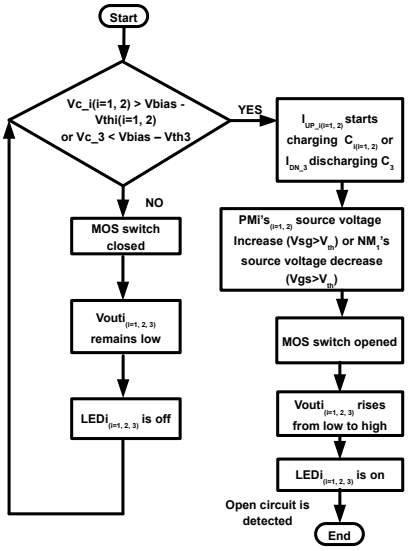


Fig. 2. The operation flow of Broken Line Detector.

To generate Vbias, $\mathrm{V_{cc}}$ is divided by two series resistors, i.e., $\mathrm{R_4}$ and $1.66\mathrm{R_4}$. The reason of the proportion between the two series resistors is set the Vbias voltage between those of $\mathrm{CELL_2}$ and $\mathrm{CELL_3}$ positive electrodes.

$\mathrm{PM_1}$ and $\mathrm{PM_2}$ are PMOS transistors, where the gate is driven by Vbias. Their sources are coupled to the positive electrodes of $\mathrm{CELL_1}$ and $\mathrm{CELL_2}$, respectively. $\mathrm{I_{UP\_1}}$ and $\mathrm{I_{UP\_2}}$ are pull-up currents which are designed much larger than $\mathrm{I_{B\_1}}$ and $\mathrm{I_{B\_2}}$, namely the corresponding current sinks.

If $L_1$ and $L_2$ are good, $PM_1$ and $PM_2$ are closed. Vout1 and Vout2 stay low. If $L_1$ or $L_2$ is open, $I_{UP\_1}$ or $I_{UP\_2}$ starts to charge the capacitor $C_1$ or $C_2$, and raise $V_{c\_i(i=1,2)}$ to turn on $PM_1$ or $PM_2$, respectively. Vout1 or Vout2 will then be pulled up from low to high to indicate that a broken line is detected.

The open circuit detection for the line of the top battery cell is different. $NM_1$ is an NMOS, where the gate voltage is driven by Vbias, and the source is connected to the positive electrode of $CELL_3$. $I_{DN\_3}$ is a current sink much larger than $I_{B\_3}$. If $L_3$ is good, $NM_1$ is closed and Vout3 remains low. If $L_3$ is open, the capacitor $C_3$ starts to discharge by $I_{DN\_3}$ and pull-down $V_{c\_3}$ to turn on $NM_1$. The drain voltage of $NM_1$ is then pulled low, and the Vout3 will turn high by the inverter.

In short, any line coupled to the cells of a battery string can be independently detected to learn if the connection is good.

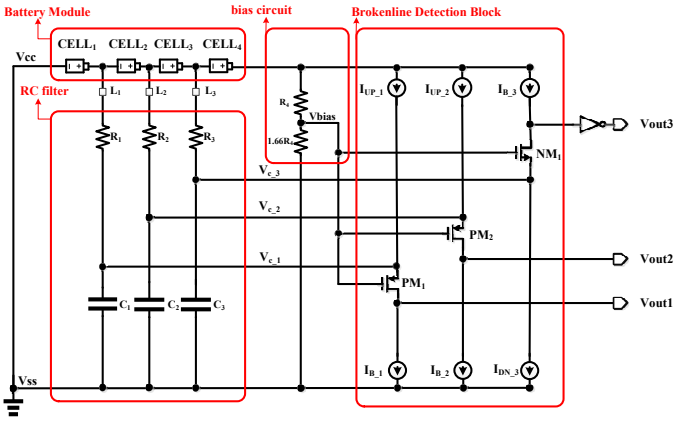


Fig. 3. Block diagram of a four cells Li-ion battery protection circuit.

## III. EXPERIMENT AND MEASUREMENT

A system prototype setup for the proposed Broken Line Circuit and battery module (ICR18650-26H) measurement is shown in Fig. 4. The results are shown in Fig. 5. In Fig. 5 (a) shows the scenario when all lines are good. Fig. 5 (b) shows $L_1$ is open, Fig. 5 (c) shows $L_1$ and $L_3$ are open, and Fig. 5 (d) shows $L_1$, $L_2$, and $L_3$ are all open. The $LEDi_{(i=1,2,3)}$ on-off states in Fig. 5 indicate whether the proposed Broken Line Detector successfully detect the open circuits of all the lines. A comparison between the proposed Broken Line Detector and several prior works is tabulated in Table I, where our design demonstrates the full functionality of open line defection for the widest battery voltage range.

TABLE I
PERFORMANCE COMPARISON OF BROKEN LINE DETECTOR

| | [3] | [4] | [5] | this work |
|---|---|---|---|---|
| Year | 2011 | 2013 | 2011 | 2018 |
| Multi-cell detection | N/A | Yes | Yes | Yes |
| Voltage broken line detection | Yes | Yes | Yes | Yes |
| Voltage range (V) | N/A | 0 – 14.4 | 0 – 14.4 | 0 – 16.8 |

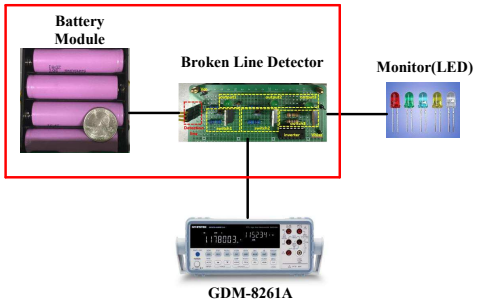


Fig. 4. Measurement setup of the proposed Broken Line circuit.

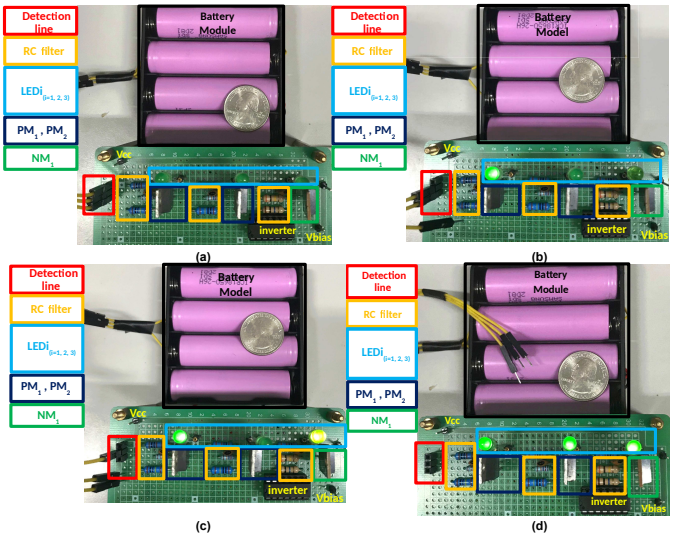


Fig. 5. The measurement results with (a)none, (b)1, (c)2, (d)3 battery cells disconnected.

## REFERENCES


[1] Z.-Y. Hou, P.-Y. Lou, and C.-C. Wang, "State of charge, state of health, and state of function monitoring for EV BMS," *IEEE Inter. conf. on International Conference on Consumer Electronics (ICCE),* pp. 310-311, Jan. 2017.

[2] Y. Wang, Z. Han, and J. Shi, "One cell Lithium-ion battery protection IC," *IEEE Inter. conf. on Industrial Electronics and Applications,* pp. 1427-1432, Jun. 2014.

[3] X.-P. Wang and Q.-G. Bai, "Line broken detection circuit of battery and detection method thereof," Chinese Patent CN102967788B, Sep., 2011.

[4] M. Jiang and Y.-Q. Yang, "Disconnection protection circuit for lithium power battery pack," Chinese Patent CN203243028U, Mar., 2013.

[5] K. Junichi, "Protective semiconductor apparatus for an assembled battery, a battery pack including the protective semiconductor apparatus, and an electronic device," Chinese Patent CN2011843801, Jul., 2011.