Application Note

MOSFET Replacement Strategy for BMS Applications

(AN-001)

Version	Date	Author	Approved by
A	15-July-2025	Harshil Mehta	Jayaprasad
B	14-November-2025	Harshil Mehta	Jayaprasad

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1. Introduction

Battery Management Systems (BMS) commonly use parallel MOSFETs to handle high currents while maintaining acceptable power dissipation and thermal performance by offering the lowest conduction resistance. However, Sagar Semiconductors' advancing MOSFET technology now enables designs with fewer parallel devices, offering benefits in cost, board space, and system complexity. This application note provides a systematic approach to evaluate and implement MOSFET replacement strategies.

2. Key Parameters for MOSFET Selection

While selecting MOSFETs for BMS applications, several parameters of the MOSFETs need to be given high importance. These critical parameters are listed below:

1. **Drain-Source Voltage (V_{DS}):** The value of V_{DS} must exceed maximum cell voltage plus safety margin. The safety factor taken would be 1.5 to 2 times the maximum operating voltage. This would ensure that the MOSFETs would be able to block the battery voltage successfully despite occasional surges. For the typical BMS requirement of 48 V battery, generally MOSFETs having V_{DS} value greater than 100 V can be preferred.

2. **Continuous Drain Current (I_D):** The value of the Drain Current is based on thermal limitations at operating temperature. The design engineer should consider the current derating with respect to junction temperature.

3. **On-state Resistance ($R_{DS(on)}$):** This is the primary driver of conduction losses happening inside MOSFETs. This parameter is typically specified at V_{GS} = 10 V and 25 °C. To reduce the conduction losses, the value of on-state resistance should be as low as possible.

4. **Gate Charge (Q_g):** Gate Charge affects switching losses and drive requirements. The total gate charge is given in the datasheet at rated V_{DS} and I_D. Another related parameter Gate-drain charge (Q_{gd}) is responsible for switching performance considering it controls turn-on and turn-off time.

3. Thermal Analysis and Calculations

The load current flowing through MOSFETs results in conduction losses that in turn produces heat and raises the temperature of MOSFETs. In the absence of proper thermal analysis and heat dissipation arrangement, the heat can cause significant temperature rise that can increase the junction temperature to rise beyond the specified limit in the datasheets, resulting in the damage of the MOSFETs.

3.1 Power Dissipation Calculation

The power dissipation is calculated using the following formulas:

Conduction Losses if only one MOSFET is conducting load current,

$$P_{cond} = I_{load}^2 \times R_{DS(on)} \times duty_{cycle} \qquad \text{... (1)}$$

Total Conduction Losses for parallel MOSFETs with current sharing,

$$P_{cond_{total}} = \frac{I_{load}^2 \times R_{DS(on)} \times duty_{cycle}}{N_{parallel}} \qquad \text{... (2)}$$

Where,

- I_{load} = Load current (A)
- $R_{DS(on)}$ = On-resistance at operating temperature (Ω)
- $N_{parallel}$ = Number of parallel MOSFETs
- $duty_{cycle}$ = Fraction of time conducting

The value of $duty_{cycle}$ is 1 for BMS application since it does not involve frequent switching.

3.2 Temperature Rise Calculation

Based on the power dissipated in MOSFETs, the temperature rise in junction temperature from ambient temperature is calculated using following formulas:

$$\Delta T = \left(P_{cond_{total}} * \theta_{ja}\right) \qquad \text{... (3)}$$

$$T_j = T_c + \left(P_{cond_{total}} * \theta_{jc}\right) \qquad \text{... (4)}$$

Where,

- ΔT = The temperature rise in the junction temperature from ambient temperature
- Tj = Junction temperature
- Tc = Case temperature

4. Methodology for Replacement

To replace the existing the MOSFETs with a new one, analysing the existing design and then evaluating the new design is required. The existing design is analysed using a two-fold approach: 1) Characterise existing design 2) Define requirements

4.1 Characterise Existing Design

In the first step, the actual current per MOSFET is measured, followed by recording junction temperatures under load. Based on the actual current per MOSFET, power dissipation per device is calculated. Then, the cumulative power dissipation is MOSFETs is calculated.

4.2 Define Requirements

- Maximum allowable junction temperature
- Target power dissipation budget
- Available board space and thermal management

5. Example

Suppose in the existing BMS design, 8 MOSFETs (8 in charge and discharge channel each) of TO-263 package having ratings of 100 V, 168 A, 0.0042 Ω are used. The following are the ratings of the BMS and MOSFETs:

Parameter	**Value**
Battery Voltage (V)	48
Battery Max Current (A)	100
MOSFET V_{DS} Rating (V)	100
MOSFET Continuous Current (A)	120
MOSFET $R_{DS(ON)}$ (Ω)	0.0042
No. of MOSFETs in Parallel	**8**

Table 1: Electrical characteristics of the existing MOSFET

The values of Thermal Resistance of Junction to Case and Junction to Ambient along with the maximum junction temperature are taken from the datasheet. MOSFET Case Temperature Observed are to be defined by the hardware designer.

Maximum Operating Junction Temperature is the temperature defined by the designer considering the margin of safety (25 °C in this case) and maximum allowable temperature (150 °C) from datasheet.

Parameter	Value
Thermal Resistance RθJA (°C/W)	62
Thermal Resistance RθJC (°C/W)	0.55
MOSFET Case Temperature Observed (°C)	**110**
MOSFET maximum Junction Temperature (°C)	150
Maximum Operating Junction Temperature (°C)	**125**

Table 2: Thermal characteristics of the existing MOSFET

Based on the characteristics given and the equations 1 to 4, the results will be as below:

Parameter	Results	Remarks
Total Power Dissipation (W)	5.3	From eq. 2
Current per MOSFET (A)	12.5	Total current/no of MOSFETs
Power Dissipation per MOSFET (W)	0.656	From eq. 1
Temperature Rise per MOSFET (°C)	40.7	From eq. 3
Junction Temperature (Tj) (°C)	**110.4**	From eq. 4
Available margin for Operating Junction Temperature (°C)	**14.6**	From table 2
Resultant Rds(on) per MOSFET (Ω)	0.00053	

Table 3: Power dissipation and temperature rise in existing MOSFETs

As per the table 3, the power dissipation per MOSFET will be 0.656 W, and it will result in the 40.7 °C Temperature Rise per MOSFET. If the case temperature observed as 110 °C then junction temperature will be 110.4 °C which leaves the available margin of 14.6 °C for MOSFETs to operate.

Suppose the hardware designer decides to replace these MOSFETs with Sagar Semiconductors' SBN10168 MOSFETs that have TO-263 package and 100 V, 168 A, 0.0037 Ω ratings. This part number possess following electrical and thermal characteristics.

Parameter	**Value**
Battery Voltage (V)	48
Battery Max Current (A)	100
MOSFET Vds Rating (V)	100
MOSFET Continuous Current (A)	168
MOSFET Rds(on) (Ohms)	0.0037
No. of MOSFETs in Parallel	**8**
Thermal Resistance RθJA (°C/W)	62.5
Thermal Resistance RθJC (°C/W)	2.6
MOSFET Case Temperature Observed (°C)	**110**
MOSFET maximum Junction Temperature (°C)	175
Maximum Operating Junction Temperature (°C)	**150**

Table 4: Electrical Characteristics and Thermal Characteristics of SBN10168

Based on these characteristics, the power dissipation and temperature rise will be calculated as below:

Parameter	**Results**	**Remarks**
Total Power Dissipation (W)	4.6	From eq. 2
Current per MOSFET (A)	12.5	Total current/no of MOSFETs
Power Dissipation per MOSFET (W)	0.578	From eq. 1
Temperature Rise per MOSFET (°C)	**36.1**	From eq. 3
Junction Temperature (Tj) (°C)	**111.5**	From eq. 4
Available margin for Operating Junction Temperature (°C)	**38.5**	From table 2
Resultant Rds(on) per MOSFET (Ω)	0.00046	

Table 5: Power dissipation and temperature rise in the replacements

As it can be observed in the table 5, the temperature rise in SBN10168 will be less as compared to existing MOSFETs. Also, as SBN10168's maximum operating junction temperature is defined as 150 °C, this leaves more available margin for operating junction temperature.

5.1 Accurate calculations

For accurate calculations, $R_{DS(on)}$ needs to be readjusted at the T_j using the following equation:

$R_{DS(on)}@Tj = R_{DS(on)}@\,25\,°C \times [1 + \alpha * (Tj - 25)]$ ... (5)

Where 'α' is the temperature coefficient (typically 0.005-0.007/°C).

Power dissipation and temperature rise can be recalculated using iterative methods considering the $R_{ds(on)}$ @ Tj until the values converge.

Similarly, if MOSFETs have unequal current sharing, the power dissipation needs to be recalculated accordingly.

6. Conclusion

This methodology enables systematic MOSFET replacement while maintaining thermal performance. Key success factors:

- Account for RDS(on) temperature dependence
- Include current sharing factors in calculations
- Validate with thermal measurements
- Maintain adequate safety margins (>10°C junction temperature margin)
- Gate driver resistance tuning

The SBN10168 example demonstrates 13% power reduction and 64% increase in thermal margin, enabling potential reduction in parallel device count for future designs.