Enhanced Diagnostic and Protection of Motor Drivers to Assist Robust System Development

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• Career
  – BS in Electrical Engineering – Purdue University
  – 2000: Joined TI as a system engineer in Op Amp team
  – 2000: Moved to Audio Amplifier team late in the year
  – 2010: Motor Drive Business Unit was formed and joined as Application Manager

• Expertise
  – 18 years experience as system/application engineer defining and supporting analog power devices
Detailed Agenda

• Trend of Automotive application and Motor Drivers
  – Autonomous driving, Electrical vehicle
  – Example applications: EPS, Braking

• Technical Deep Dive – architecture, value position and system implementation
  – Serial Communication integrity
  – Over current of Power FETs
  – Open and Short of Motor Connection

• TI solution with PMIC + Motor Driver for robust system design
  – PMIC diagnostic can connect Motor Driver protection
Innovative Automotive Solutions: more electrification and motorized systems
Trend – Example: Power Steering system

Motorized system

Direct mechanical steering wheel

Hydraulic power steering

Electrical Power Steering (EPS)

Mechanical back up (human) assist

Advanced electrification

Autonomous driving
Trend – Example: Braking system

Traditional Vacuum Boosters assist braking force, and the vacuum needs engine.

Replace the engine/vacuum with a Brushless DC Motor

Motorized system

No engine or engine stop

Electrically assisted brake system

PMIC → MCU → DRV → M

Vacuum booster

TI Information – Selective Disclosure
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Over current of Power FETs
Tech Deep Dive: Over Current detection – System Requirements (during motor operation)

- Requirement: Detect over current
- Requirement: Shutdown gate driver to stop the shoot-through current
- Requirement: Report the fault to MCU

Potential effect: External power FETs potentially get damaged or over-heating if the shoot-through current condition lasts long.
Tech Deep Dive: Over Current detection of Power FETs

System Requirement

- Detection of power FETs from overcurrent
- Immediate shutdown of power FETs after the fault detection
- Fault is reported to MCU

Advantages

- Reduction of external components for overcurrent protection.
- Programmability of features allows user to change thresholds and times to meet system requirements.

Solution

Integrated comparators to monitor drain-source voltage of external power FETs.
Advantages:
- Fully integrated solution → Reducing external components and fast response

Advantages:
- 2 path fault reporting to MCU

Advantages:
- High accuracy threshold (10% @ Vth = 0.5V)
Tech Deep Dive: Over Current detection – Threshold – is accuracy important?

**Example system requirement**

![Diagram of FET circuit with current levels](image-url)

- **$R_{DS_{ON}} = 10m\Omega$**
- **Typ $50A = 0.5V / 10m\Omega$**

**Over current**
- $+30\% = 65A$
- $+10\% = 55A$
- $-10\% = 45A$

**Normal current**
- $-30\% = 35A$

- True over current may not be detected even exceeding over current
- False over current may be detected even in normal current level
Tech Deep Dive: Over Current detection – Selecting Parameter (Timing)

Ex) DRV8305-Q1 Datasheet

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>t_{VDS}</td>
<td>0 μs</td>
</tr>
<tr>
<td></td>
<td>1.75 μs</td>
</tr>
<tr>
<td></td>
<td>3.5 μs</td>
</tr>
<tr>
<td></td>
<td>7 μs</td>
</tr>
<tr>
<td></td>
<td>5 μs</td>
</tr>
<tr>
<td></td>
<td>1.75 μs</td>
</tr>
<tr>
<td></td>
<td>3.5 μs</td>
</tr>
<tr>
<td></td>
<td>7 μs</td>
</tr>
<tr>
<td></td>
<td>7 μs</td>
</tr>
</tbody>
</table>

Advantages:
- SPI Configuration (flexibility for the combination of FET and system requirement)

Comparator output is ignored during \( t_{\text{blank}_{VDS}} \)
Comparator output is ignored if the fault condition is shorter than \( t_{\text{deg}_{VDS}} \)
SPI status bit VDS_HS is set to 1 if the fault condition is longer than \( t_{\text{deg}_{VDS}} \)
Serial Communication integrity
Tech Deep Dive: Data Communication Integrity - Typical implementation

Typical Implementation

<table>
<thead>
<tr>
<th>Implementation</th>
<th>MCU</th>
<th>Data</th>
<th>IC</th>
<th>Potential effect: Data error over MCU communication can cause incorrect device setting of IC or incorrect status reporting from IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only Address + data</td>
<td>MCU</td>
<td>Address + data</td>
<td>IC</td>
<td>No error detection by device, MCU read back</td>
</tr>
<tr>
<td>Parity added to a frame</td>
<td>MCU</td>
<td>Address + data</td>
<td>IC</td>
<td>Low or middle data integrity: two bit errors are not detected</td>
</tr>
<tr>
<td>CRC added to a frame</td>
<td>MCU</td>
<td>Address + data</td>
<td>IC</td>
<td>Middle or High data integrity, but increase SPI length affecting communication band width</td>
</tr>
</tbody>
</table>
Tech Deep Dive: Device Configuration Data Integrity – Typical implementation

Potential effect: Data error of register map can cause incorrect device setting of IC

Typical Implementation

Read back of registers

MCU

Read

IC

MCU/Software load is increased. Higher SPI bandwidth is required during motor operation.
Tech Deep Dive: Device Configuration Data Integrity – Solution - Configuration Data CRC

CRC runs periodically to monitor the register map, and the device reports to MCU when a fault is detected.

Advantages:
- Real time monitor of device parameters without extra resource of MCU.
- High error detection capability using CRC
Open and Short of Motor Connection
Tech Deep Dive: Short Detection of Motor Connection (in development)

<table>
<thead>
<tr>
<th>System Requirement</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Short detection of motor connection (to GND and to Battery) before running motor</td>
<td></td>
</tr>
</tbody>
</table>

**Advantages**

• Reduction of external components for fault detection  
• MCU can take action to avoid system damage before the operation

![Diagram showing GND short detection and Battery short detection]

Short to battery  
Short to GND
Tech Deep Dive: Short Detection of Motor Connection - System requirement (at power up)

Requirement: Detect failure mode at power up before motor starts running.

Potential effect: External power FETs get damaged if the shoot through current condition lasts long.

Requirement: No motor current is expected during the diagnostic.

Requirement: Report the fault to MCU so that MCU can take the action (no PWM is driven in case of fault).
Customer need to know SHx Leakage current (typically not defined in datasheet) to decide the resistance parameters and error detection threshold.
Tech Deep Dive: Short Detection of Motor Connection – Solution – Short to GND

Compressor input voltage goes low and the comparator output is low. No fault is reported.

Comparator input voltage exceeds $V_{TH}$ and the comparator output is high. A fault is reported to MCU via SPI and nFAULT pin.
Tech Deep Dive: Short Detection of Motor Connection – Solution – Short to Battery

 Comparator input voltage goes low and the comparator output is low. No fault is reported.

 Comparator input voltage exceeds $V_{TH}$ and the comparator output is high. A fault is reported to MCU via SPI and nFAULT pin.
Tech Deep Dive: Open Load Detection - System requirement (at power up)

Requirement: Detect failure mode at power up before motor starts running.

Potential effect: Expected motor control is not available in the system.

Requirement: No motor current is expected during the diagnostic.

Requirement: Report the fault to MCU so that MCU can take the action (no PWM)

TI Information – Selective Disclosure
Tech Deep Dive: Open Load Detection (in development)

**System Requirement**

- Open detection of power FETs or Motor load before running motor
- Fault is reported to MCU

**Solution**

- Diagnostic current injection to load

**Advantages**

- Reduction of external components for fault detection
- MCU can take action to avoid system damage before the operation
Detailed Agenda

• Trend of Automotive application and Motor Drivers
  – Autonomous driving, Electrical vehicle
  – Example applications: EPS, Braking

• Technical Deep Dive – architecture, value position and system implementation
  – Serial Communication integrity, Clock Monitor
  – Over current of Power FETs
  – Open and Short of Motor Connection

• TI solution with PMIC + Motor Driver for robust system design
  – PMIC diagnostic can connect Motor Driver protection
Motor Driver System Consideration

Requirement: Detect failure mode while motor is running, independent from MCU

Requirement: Shutdown motor operation independent from MCU

Potential effect: Unintended motor assist to the system.

MCU potentially sends unintended PWM control signals to Gate Driver.
Motor Driver System Consideration – Typical implementation

- Battery
- Power Supply
- MCU
- Power
- Gate Driver
- SW
- Special signal or additional communication interface
- MCU reset in case of failure
- Watchdog Timer IC
- External logic and level shifter
- PWM
- Texas Instruments
**Motor Driver System Consideration – Solution TPS6538x + DRV32xx**

**DRV32xx : Shutdown path**

Note) Shutdown implementation will depend on the system requirement, such as independency or redundancy.

**TPS6538x : Watchdog Timer, MCU error signal monitor and driver shutdown control**
DRV3xxx family Collateral and Training

**DRV3205-Q1 Electronic Power Steering Design Guide**  
Search "SLVA830" on ti.com

**White paper on Analog Functional Safety**  
Search "SLYY111" on ti.com

**DRV3000 Motor Driver for Functional Safety Applications training**  
http://training.eeworld.com.cn/TI/video/7363

**Application Notes**

- DRV3201 Current Sense
- Q&A Watchdog Timer DRV3205-Q1
- DRV3201 Boost Converter
- DRV3205-Q1 Applications in 24-V Automotive Systems
- Backwards Batteries: Protecting Automotive Motor-Drive Systems from Reverse Polarity Conditions