Intelligent Power Devices
Smart Switches for Automotive Exterior Lighting

Keith Larson
Product Marketing Manager - Analog and Power Devices
How I Got Here...

Education
- BSET: Purdue University, December 1990
- MEng: Cornell University, May 1996
  - Emphasis in Control Systems and Computer Architecture

Experience
  - 5 years in Manufacturing Engineering, Test Development, Circuit Development
  - 12 years in IC Architecture and Development
    - IC specification and requirements development, evaluation
    - Circuit development and simulation, analysis, IC design support
    - Powertrain, braking, crash-sensing, networking and body ECU expertise
- Renesas Electronics America Inc. (2008 +)
  - Senior Marketing Manager for Analog and Power Products
  - Mixed-signal market development for North America
Renesas Technology & Solution Portfolio
Analog and Power Automotive Products

**Application-Optimized Processes**
- 40 V – 120 V devices to address major automotive systems needs
- Low voltage family optimized for $Q_{gd} \times R_{ds(on)}$
- Separate family optimized for pure $R_{ds(on)}$ performance
- Low thermal resistance packaging technologies

**Inverter Driver Solutions for HEV/EV**
- 650V @ 200A, 300A & 400A (bare die)
- Class-leading turn-off loss performance
- High-speed, short-circuit rated, and low $V_{ce(on)}$ optimized

**Protected High-side Drivers**
- 6 mΩ - 90 mΩ, scalable solutions for exterior lighting, relays, solenoids...
- Ultra-low key-off leakage current performance
- Robust protection against short-circuit conditions

**Products Addressing All Major Vehicle Systems**
- Crash-sensing chipset for airbag applications
- Powertrain output load drivers, direct gas injection...
- Battery management ICs, MOSFET gate drivers
- Micro-isolator IGBT drivers for high-voltage isolation
- Multi-chip Package devices for switch input and load control
‘Enabling The Smart Society’

- **Challenge:**
  “The Smart Society requires automotive systems that can reliably drive bulbs, relays, solenoids and other high-current loads without succumbing to the safety risks posed in such applications. All of this intelligence cannot come at the price of consuming energy in times when the device is not in use.”

- **Solution:**
  “Intelligent power devices provide a robust, ‘green’ solution for driving today’s demanding automotive loads and providing critical fault protection and detection from the harsh automotive environment. Efficient designs practically eliminate any off-state current drain from the vehicle energy source.”
Agenda

- Motivation Behind Market for Intelligent Power Devices (IPD)
  - Exterior Lighting Application Overview
  - Nuances of Driving Incandescent Bulbs
  - Keeping the Switch Safe (Safe Operating Area)
  - Diagnosing Fault Conditions
  - Reducing System Cost and Complexity

- Key Performance Criteria for Automotive IPDs
  - Short Circuit Protection
  - Current Sense Accuracy
  - Key-off Leakage Current
  - Low Battery Operation
  - Under-voltage Shutdown and Recovery
  - Open Load Detection
  - Electromagnetic Compatibility (EMC)

- IPD Solutions from Renesas
  - Gen 1 Review
  - Gen 2 Roadmap
Motivation Behind Market for Intelligent Power Devices (IPD)
Exterior Lighting Application Overview

- **55W High beam**
- **55W Low beam**
- **55W Fog Lamp**
- **21W**
- **10W**

**Micro.**

- **REG**
- **PWM OUT**
- **VDD**
- **Pre driver**
- **MUX**
- **PWM OUT**
- **ANI**

**UPD166010**

- **VCC**
- **IN OUT**
- **IS**
- **OUT**

- **UPD166009**
- **IN OUT**
- **IS**
- **OUT**

**UPD166014**

- **PWM OUT**
- **ANI**
- **Port**

**UPD166013**

- **VCC**
- **IN1**
- **OUT1**
- **IS2**
- **IS1**

**UPD166011**

- **VCC**
- **IN1**
- **OUT1**
- **IS2**
- **IS1**

- **Parking**
- **Position**
- **Room lamp, step lamp etc.**

- **Front 21W**
- **Side 5W**
- **Rear 21W**

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Nuances of Driving Incandescent Bulbs

- Incandescent bulbs have an ‘in-rush’ characteristic
  - Cold filament is low impedance
  - Filament heats quickly due to current
  - Commonly modeled as a parallel RC network

- Output must be sized to survive the peak in-rush current
  - Cannot go into any protective operation, as this would extend the turn-on time and increase power dissipation depending on protective methods
  - In-rush current can be many times greater than steady-state current
  - Optimal protective schemes can adjust between these two operating conditions

Example of a model for an automotive grade, 168-type bulb
Keeping the Switch Safe (Safe Operating Area)

Graph to $I_L(V_{ON})$ to demonstrate compliance with SOA curve.

- **Nominal Current**
- **Inrush Current**
- **Typical lamp switch**
- **Typical resistive load**
- **RDS(on) Limited**
- **Current Limited**
- **Power Limited**
- **Voltage Limited**
Diagnosing Fault Conditions

■ Terminal Short
  ● Short close to the ECU* output connector
  ● Immediate high current condition

■ Load Short
  ● Short at the load but through the wiring harness
  ● Immediate high current, but reduced by the wire harness resistance and inductance

■ Intermittent Short
  ● Caused by moisture or wire pinch
  ● Often high impedance and low current

■ Open Load
  ● Can occur when power is on or off

■ Short to Battery
  ● Can be caused by connector reversal or human error at vehicle assembly

* ECU = Electronic Control Unit
Reducing System Cost and Complexity

- IPDs reduce system cost by minimizing PCB footprint
  - Control circuitry can be mounted in the same package used in discrete load switch applications

- IPDs reduce system cost and increase reliability by minimizing parts count

- Discrete load switches often cannot economically provide the same level of protection
  - Thermal sense
  - Current limit
Key Performance Criteria for Automotive IPDs
A normal inrush current must not trigger current limit. In this case, the current limit, $I_{L(SC)}$, is dependent upon the output saturation voltage, $V_{ON}$. 

Typical lamp switch

Nominal Current

Inrush Current

$V_{ON(OVL)}$
**Short-circuit Protection: Power Limitation**

**ΔTch**

- **ΔTch** protection for Power Limitation
  - **ΔTch** detection with 2 temperature sensors to inhibit large temperature differential on die

![Power MOSFET and Logic Diagram](image)

**Over current detection and latch**

- **Over current detection**
  - Shutdown immediately by over-current detection
  - **Over-current detection threshold** accounts for lamp in-rush current

"Grade A" (No failure, >1M cycles)

**ΔTch**

- **Absolute Tch Method**
  - Ref: 175°C
  - Hysteretic interval: 10°C

- **ΔTch Method**
  - Ref: 60°C

\[ \Delta T_{ch} \]

1 Tch represents the channel (i.e. junction) temperature

\[ 1 \]
Current Sense Accuracy

- Manufacturers typically use load current to diagnose proper operation and to confirm an open load fault
  - Current sensing typically involves using an op amp to provide a ratio of the output current to the host MCU via an A/D input
- Op amp input offset voltage and temperature drift limit the accuracy at low current values
  - Low current values lead to low output voltage at the op amp
  - Op amp offset and drift errors result in large errors for low current values, sometimes more than 30 to 40%
  - This large error is normally tolerable for lamps, but not LEDs
- LEDs are becoming more prevalent
  - Customers demand outputs that are useful in both lamp and LED-configured vehicles
  - Current sense must be much more accurate at low currents to diagnose LED output currents
  - 10% or better is requested
Key-off Leakage Current

- Key-off leakage current refers to the current drawn by a device even when it is off
  - Critical parameter for devices with a connection to the battery

- Each ECU represents a valve for energy consumption from the battery, much like a faucet valve on a water supply
  - Goal is to maintain the battery charge when the vehicle is off

- Typical body computer alone may have 10 or more IPDs in addition to other devices with connection to the battery!
  - Consider that there are vehicles today that are approaching 40+ ECUs in a vehicle, many of which are connected to the battery

- Off-state leakage currents must be minimized!
Low Battery Operation

- Many ECUs in a 12 V automotive application must continue to operate across a wide voltage range
- One of the most extreme voltage conditions occurs when the engine is cranking
  - In cold temperatures, the voltage can drop as low as 4 V* momentarily until the back emf of the starter motor builds and the engine begins to crank
- Critical outputs cannot be disabled during these conditions
  - Fuel pump relay, headlights and more
- IPD outputs generally are disabled as the voltage falls below the minimum guaranteed operating voltage
  - Protects the output from potential high linear power dissipation

* Exact voltage values vary somewhat across the industry, but are generally lower than 6 V
Voltage transients are plentiful in the automotive environment!
- High voltages could irreparably damage the output

One method to protect the device is to use active clamping output over-voltage shutdown
- Active clamp allows the device to protect its internal logic
- Active clamp activation allows the device to disable the output to protect the load from excessive output voltage

Many customers will dictate the required behavior for the IPD once the over-voltage condition is cleared
- Some functions require that the output automatically recover
- Others require that the output be latched off until the MCU can intervene to re-enable the output safely
Open Load Detection

- Open-load detection is typically required for reporting faults in lighting applications.

- Open-load detection can be performed by reading the output voltage:
  - When there is a small current through and large voltage across the output, then the load is open (or the output could be shorted to the reference).
  - Open-load detection is normally signaled through a discrete fault pin to the MCU.

- In small-package, pin-limited IPD applications, the MCU may use a combination of current sense and discrete open-load detection to completely diagnose an open-load condition.
Electromagnetic Compatibility (EMC)

- Connecting IPDs to automotive loads creates an antenna through the wiring harness
  - Antenna allows noise to be transmitted to and received from the environment
  - Noise generated is a function of output load current, operating frequency, switching time, stray and wiring harness inductance and other parasitic devices
- Noise cannot be realistically or economically eliminated, but must be kept to acceptable levels through careful selection of the rise and fall times
- Many customers now require IC-level EMC testing
  - Radiated Emission
    - IEC 61697-4, 150 ohm method
  - Radiated Immunity
    - IEC 62132-4, DPI method
  - Transient (or Conducted) Immunity (ISO 7637-2)
    - Generally pulses 1, 2a, 3a and 3b
  - Electrostatic Discharge (ESD) Immunity
    - AEC Q100, Human Body Model (HBM), Charged Device Model (CDM) and sometimes Machine Model (MM)

\[ V_{EMC} = L_{Parasitic} \frac{dI_{Load}}{dt_{ON(off)}} \]
Renesas Intelligent Power Devices (IPD)
IPD Development Strategy

**IPD Worldwide Market**

$650M@2009 \Rightarrow $933M@2014

- **Body**: 45%
- **Transmission**: 13%
- **Engine**: 25%
- **Brake**: 10%

**Body-IPD WW Market**

$228M@2009 \Rightarrow $416M@2014

- **Motor**: 14%
- **Relay**: 18%
- **10W**: 9%
- **21W**: 22%
- **55W**: 27%

*FRM-IPD: Function Rich Multi-channel-IPD*
IPD Development Strategy

**Body-IPD WW Market**

$228M@2009 → $416M@2014

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>55W, 27%</td>
</tr>
<tr>
<td>90%</td>
<td>10-12 mΩ</td>
</tr>
<tr>
<td>80%</td>
<td>16-20 mΩ</td>
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<tr>
<td>70%</td>
<td>60 mΩ</td>
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<tr>
<td>60%</td>
<td>30 mΩ</td>
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<tr>
<td>50%</td>
<td>10W, 9%</td>
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<tr>
<td>40%</td>
<td>21W, 22%</td>
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<tr>
<td>30%</td>
<td>90 mΩ</td>
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<tr>
<td>20%</td>
<td>Relay, 18%</td>
</tr>
<tr>
<td>10%</td>
<td>Motor, 14%</td>
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<tr>
<td>0%</td>
<td>H-bridge</td>
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</table>

*FRM-IPD: Function Rich Multi-channel-IPD*
## Gen 1.0 IPDs for Incandescent Lighting

<table>
<thead>
<tr>
<th>Load</th>
<th>Ron</th>
<th>Device</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>21W/27W</td>
<td>60mOhm</td>
<td>uPD166013, uPD166014</td>
<td>12/24pin PSOP for dual/quad</td>
</tr>
<tr>
<td>Flasher</td>
<td>25mOhm</td>
<td>uPD166011</td>
<td></td>
</tr>
<tr>
<td>55W/65W</td>
<td>10 – 13 mOhm</td>
<td>uPD166007, uPD166009, uPD166010</td>
<td>TO252 5 pin for single</td>
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<tr>
<td></td>
<td></td>
<td>uPD166019 P-ch</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>uPD166020, uPD166021</td>
<td></td>
</tr>
<tr>
<td>65W/75W</td>
<td>6mOhm</td>
<td>uPD166017</td>
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<table>
<thead>
<tr>
<th></th>
<th>Single</th>
<th>Dual</th>
<th>Quad</th>
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</thead>
<tbody>
<tr>
<td>MP</td>
<td>Sample</td>
<td>Design</td>
<td>Planning</td>
</tr>
</tbody>
</table>
ROSA (i.e. Gen 2.0) Family Roadmap

Under development

<table>
<thead>
<tr>
<th>QUAD CHANNEL</th>
<th>DUAL CHANNEL</th>
<th>SINGLE CHANNEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Quad Channel Image]</td>
<td>![Dual Channel Image]</td>
<td>![Single Channel Image]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TARGET APPLICATION</th>
<th>HEADLIGHT (55W, 65W, 75W)</th>
<th>FLASHER, TAIL LAMP, STOP LAMP (10W, 20W, 30W)</th>
<th>SIGNAL LAMP (5W, 10W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Headlight Image]</td>
<td>![Flasher Image]</td>
<td>![Signal Lamp Image]</td>
<td></td>
</tr>
</tbody>
</table>

Note: Ron values are typical values at 25° C
**ROSA Key Features and Characteristics**

- **Scalable**
  - Wide selection of devices from single channel to quad channel
  - Broad range of \( \text{Rdson} \)
    - 6 to 90\( \text{mΩ} \)*

- **Flexible**
  - Commonized MCU interface for standardized software
  - Variety of \( \text{Rdson} \) sizes with same package and pinout

- **Robust**
  - Current limitation
  - Power dissipation control
  - Over-temperature
  - Under-voltage

- **Electrical parameters**
  - Operating Voltage: 4.5V to 28V, load dump: 42V
  - Standby current: 3\( \mu \text{A} \) (Single Channel) / -40°C to +85°C
  - Output leakage current: 5\( \mu \text{A} \) max, \( \text{Ta} = -40°C \) to +105°C
  - Current sense down to 0.1 A

- **Microcontroller Interface**
  - 3.3 V compatible
  - Analog current sense and diagnostic

- **Overload Protection**
  - Over-current latch
  - Power dissipation control with current limitation
  - Over-temperature shutdown

- **Under-voltage Lockout**

- **Off-state Active Clamp**: 30V min.

*\( \text{Ron} \) values are typical values at 25°C
World-class Current Sense Performance with SMASH\(^1\) Family Extension

- Same operating and protection features as ROSA

- Improve KILIS\(^2\) using “offset cancellation”
  - Allow measurement of current sense offset at any time to improve accuracy of current sense measurement
  - Target spec: +/- 5% accuracy over full load current range

- Smaller packages: Jedec MO-153 (TSSOP)
  - Exposed pad type
  - Body size
    - 14 pins: 4.4 mm x 5 mm
    - 28 pins :4.4 mm x 7.8 mm
  - Pin pitch: 0.65 mm

\(^1\) Smart Support function for High accuracy KILIS
\(^2\) Industry standard term for current sense gain, pronounced “key-less”
Smart Support Function for Accurate KILIS

- Op amp is main cause of KILIS tolerance and temperature drift
- Additional mode routes the offset voltage of internal op amp to the current sense output
- MCU reads offset value and stores it as a calibration value
- MCU calculates “pure KILIS” by subtracting calibration value from current sense value
- Re-calibration can be performed as needed during BCM operation
Evaluation Development Support Tools

- Customer evaluation boards are available for both the 12-pin and 24-pin HSSOP devices
  - Independent source and sense pins for accurate measurements
  - Prototype area for mounting external components according to the evaluation needs
Renesas IPDs Offer the Industry’s Best Solution for Smart Switches!

- Robust protection from severe short-circuit conditions
  - Current limit, thermal limit and thermal toggle

- Industry-leading KILIS performance through advanced SMASH family of devices

- Aggressive key-off leakage currents that bring single-digit microamp off-state battery leakage current

- Complete suite of diagnostics for reporting fault conditions

- Tuned rise and fall times for optimal EMC performance

- Broad selection of products for a completely scalable solution
Questions?
‘Enabling The Smart Society’

- **Challenge:**
  “The Smart Society requires automotive systems that can reliably drive bulbs, relays, solenoids and other high-current loads without succumbing to the safety risks posed in such applications. All of this intelligence cannot come at the price of consuming energy in times when the device is not in use.”

- **Solution:**
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Please Provide Your Feedback...

- Please utilize the ‘Guidebook’ application to leave feedback

- Ask me for the paper feedback form for you to use...