DESIGN & IMPLEMENTATION OF ADVANCED SR CONTROL FOR LLC RESONANT CONVERTER USING UCD3138A + UCD7138
Agenda

• UCD3138A – Digital PWM Controller

• UCD7138 Functional Block Diagram

• SR waveforms in different conditions

• UCD3138A + UCD7138 Test Waveforms
UCD3138A – Digital PWM Controller

**Features**

- 3 Independent Feedback Loops
- 16MHz Error Analog to Digital Converter (EADC)
- 14-bit (effective) DAC for Control Loop Reference
- Dedicated PID Hardware (2p/2z configurable)
- 8 High Resolution DPWM Outputs (250ps Pulse Width Resolution)
- 2MHz Max Switching Frequency
- High Performance 31.25MHz, 32-bit ARM7 Processor
- 14 Channel, 12-bit, 265ksps General Purpose ADC (*Improved INL*)
- 2 UARTs + PMBus Interface
- **UART Auto-baud rate adjustment for robust communication (no missed messages)**
- 7 50ns Analog Comparators, Cycle-by-cycle \( I_{\text{LIMIT}} \)
- On-chip (BOD / POR), Single Supply Operation (3.3V)
- External Interrupt + Fault Input & Output
- Input Voltage Feed-forward
- Integrated Copper Trace Current Sensing
- -40C to 125C Extended Temp Range
- **Synchronous Rectifier Dead Time Optimization Peripheral**

**Applications**

- 48Vin Isolated DC/DC Converters
- Offline AC/DC and Isolated DC/DC Power Supplies
- PFC, Phase Shifted Full Bridge, Two Switch Forward, Hard Switching Full Bridge, and Resonant LLC

**Benefits**

- Fully Programmable and Customizable Solution with Control Architecture Optimized for Power Supply Applications
- Independent, High Speed Power Supply Loop Control, separated from Housekeeping Microcontroller
- Programmable Hardware for High Speed Functions (Mode Switching, Voltage Feedforward, Constant Current, etc.)

**Diagram:**

- Configurable State Machine for Loop Control
  - (Fully Programmable, GUI Configuration Support)
- ARM Microcontroller
  - (Fully Programmable MCU)
- Communication

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UCD3138A + UCD7138 Advanced SR Control

**Features**

**UCD3138A with synchronous rectifier dead time minimization**
- Read body diode conduction time through digital I/O pin
- Cycle-by-cycle measurements
- 4 ns measurement resolution
- Microprocessor interrupt
- Configurable detection windows
- Fast configurable negative current protection
- Configurable sequential fault counter
- Companion driver available for minimal component count and ease of implementation

**UCD7138 low side MOSFET driver with body diode conduction sensing**
- Low Side MOSFET gate driver with Body diode conduction time sensing
- 4 A peak source and 6 A peak sink drive current
- Digitally Reported Body Diode Conduction Time (DCT)
- MOSFET turn on edge optimization
- Up to 2 MHz operation frequency
- 4.5 V to 18 V supply range
- Fast rise/fall time (5ns) and propagation delay (14ns)
- Under Voltage Lockout (UVLO)
- VDS sensing voltage < 45 V
- Package: 6 pin DRS (3 mm x 3 mm WSON-6 package with exposed thermal pad)

**Benefits**

- Maximize system efficiency by minimizing MOSFET body diode conduction time
- Robust fast negative current protection
- Simple interface
  - Minimum component count
  - No external sense element
  - Easy layout
- Superior to $R_{DSon}$ sensing techniques
  - Better accuracy across entire load range
  - No minimum on time requirement
  - No parasitic L & R concerns

**Applications**

- Half Bridge or Full Bridge LLC converters
- Hard Switching Full Bridge Converters
- Diode Emulation
UCD7138 and UCD3138A hardware connection
# UCD7138 Pin functions

## TERMINAL

<table>
<thead>
<tr>
<th>NAME</th>
<th>NO.</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN</td>
<td>1</td>
<td>I</td>
<td>Input: Gate driver input. This pin should be connected directly to one of the UCD3138A DPWM outputs.</td>
</tr>
<tr>
<td>DCT</td>
<td>2</td>
<td>O</td>
<td>Body diode conduction time report: Standard digital IO. Pulled high internally. Output low when body diode conducts. This pin should be connected to the DCT0 or DCT1 pin on UCD3138A. Some noise filtering may be needed on this pin at the UCD3138A side.</td>
</tr>
<tr>
<td>VCC</td>
<td>3</td>
<td>P</td>
<td>IC supply: External bias supply input. Supply range 4.5V to 18V. A ceramic bypass capacitor of at least 1uF should be connected between VCC pin and the GND pad as close as possible.</td>
</tr>
<tr>
<td>OUT</td>
<td>4</td>
<td>O</td>
<td>Gate driver output: Integrated push-pull gate driver for one or more external power MOSFETs. Typical 4A source and 6A sink capability. Output voltage is rail-to-rail with VCC. This pin should be connected to the gate terminal of the SR MOSFETs.</td>
</tr>
<tr>
<td>VD</td>
<td>5</td>
<td>I</td>
<td>Drain voltage: Connect this pin as close as possible to the controlled MOSFET drain pad. This pin is connected to the diode conduction detection comparators internally. The comparator has a -0.15V threshold to detect body diode conduction. A 20Ω resistor should be connected between VD pin and MOSFET drain terminal to limit the current.</td>
</tr>
<tr>
<td>CTRL</td>
<td>6</td>
<td>I</td>
<td>Rising edge optimization control: connect this pin to ground to disable rising edge optimization; leave this pin floating or connect to logic high to enable rising edge optimization.</td>
</tr>
<tr>
<td>GND</td>
<td>7</td>
<td>G</td>
<td>Power Pad/GND: The exposed pad on the bottom of the package enhances the thermal performance of the device. This pad is device ground reference.</td>
</tr>
</tbody>
</table>
System block diagram

Table 1. Truth Table for CTRL Pin Function

<table>
<thead>
<tr>
<th>CTRL PIN CONFIGURATION</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 V or ground</td>
<td>Turn-on optimization disabled</td>
</tr>
<tr>
<td>3.3 V or floating</td>
<td>Turn-on optimization enabled</td>
</tr>
</tbody>
</table>
Simplified System Block Diagram
Desired SR Operation for Typical Half Bridge LLC Application

(a) Below resonant frequency
(b) At resonant frequency
(c) Above resonant frequency
Typical SR Vds waveforms (without dead time optimization)

- SR turn off too late
  - Set SR on time
  - Negative current reset causes body-diode conduction

- SR turn off too early
  - Set SR on time
  - Positive current reset causes body-diode conduction

- SR turn on too early
  - Set SR on time
  - Dead time is too short; high voltage spikes can occur on the other SR

- SR turn on too late
  - Set SR on time
  - Dead time is too long; low efficiency
Body diode conduction detection

SR turnoff too early

SR turnoff too late

VD

Comparator threshold

DTC

IN

Detection window
Turn on and turn off edge optimization

**Turn off edge Case 1:** body diode conduction time too long

**Turn off edge Case 2:** body diode conduction time too short, negative current may occur

**Turn on edge Case 1:**
Gate turn on edge controlled by IN, if body diode conduction detected at IN rising edge

**Turn on edge Case 2:**
Gate turn on edge controlled by COMP1, if no body diode conduction detected at IN rising edge
Timing diagram of the DTC interface in UCD3138A
UCD3138A + UCD7138 Test Waveforms

HPCS – System Engineering
VD and DTC Waveforms on LLC – SR Turn-off Edge

No optimization, SR on time too long.

No optimization, SR on time too short.

With optimization
No optimization, SR turn on too late.

No optimization, SR turn on too early.

With optimization
Efficiency Improvements

Efficiency Improvements (Different Input Voltages)

Efficiency Improvements (%)

Load Current (A)

Vin=380V
Vin=340V
Vin=400V

Efficiency Improvements (Different Resonant Tank Errors, Vin=380V)

Efficiency Improvements (%)

Load Current (A)

Resonant Tank no Error
Resonant Tank 5% Error
Resonant Tank 10% Error
Transient response

DTC enabled
Vin=380V, Iout=0~30A, 1A/us, 20ms/20ms

- High Vds stress during heavy load to light load transient is caused by SR turn on too long.
- Filter calculated edges are based on Vout and there is some delay.
- DTC fast edge back off helps make the high Vds stress time shorter by sensing negative current fault condition.

DTC disabled
Vin=380V, Iout=0~30A, 1A/us, 20ms/20ms
Steady state operation

**DTC enabled**  
Vin=380V, Iout=15A

- Output voltage ripple and Vds stress has no big difference in steady state operation, if both dead times are well-tuned.
- With DTC, fine tuning can be simplified.

**DTC disabled**  
Vin=380V, Iout=15A
Thank You~
The voltage drop on Rdson is too small to detect and varies with layout parasitic and the type of MOSFETs being used.

In high current applications with several MOSFETs in parallel, the Rdson is so small that the MOSFETs will be turned off when the current is still large.

In the second method, it requires resonant tank information for programming the pulse width clamp value, thus requires calibration in production.