ABSTRACT

This application note provides an alternative approach to sensing the zero crossing detection aimed for customers who prefer using an auxiliary winding. The advantage of using the aux winding approach is UCC28056 application designs are more robust and have better immunity to interference from adjacent nodes. UCC28056 is a single phase PFC boost stage working on an innovative mode method, operating in transition mode (TM) during full load and transitioning to discontinuous conduction mode (DCM) during reduced load. This paper provides a comparative analysis of the current method of biasing the ZCD/CS pin voltage across the MOSFET vs the modified approach of introducing an auxiliary winding as shown in Figure 1 and Figure 2 below on a high level.
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1 Introduction

UCC28056 has a ZCD/CS pin which combines the functionality of a Current sense and the zero crossing detection into a single pin. This application note talks in depth about the more conventional method of ZCD sensing by using a separate winding. This approach is easier to implement and the signal has more immunity to the surrounding interference because the signal is not sensed across the MOSFET.

![Figure 3. direct drain approach w/o Aux winding](image1)

![Figure 4. Aux winding approach](image2)

The approach shown in Figure 4 can be used to replace Figure 3 in order to avoid any sensitivity at ZCD/CS pin. When the controller is not switching the voltage across the auxiliary winding is zero, so only the pull up-resistor contributes to the stand-by power. The impedance of the ZCD divider is high and placing it close to the ZCD/CS pin of the controller makes the signal more immune to the disturbances by the capacitive coupling from the nearby switching nodes. Although the direct drain approach eliminates the need of an aux winding the signal sensing is more complicated and the signal is prone to increased noise susceptibility. By using an aux winding approach across the inductor, these issues can be mitigated.

2 Advantages of using the AUX winding approach

The section below highlights the advantages of using the proposed auxiliary winding approach:

1. All the nodes are low impedance nodes and thus are relatively insensitive to layout, except the ZCD/CS pin.
2. Only small low-voltage resistors are required at the ZCD/CS pin and therefore the pin has a smaller parasitic capacitance to surrounding switched nodes.
3. High voltage cap is not required.
4. Lower cost.

3 Calculations for AUX winding

This section contains the calculations for the component values for this approach as mentioned in Figure 4.

- **ZCD Divider:**
  The resistor divider for ZCD/CS pin can be calculated as:
Calculations for AUX winding

\[ V_{aux} \times \frac{RZC_2}{RZC_2 + RZC_1} = V_{ZCBoRise} \]

where:
- \( V_{aux} \) is the voltage across the aux winding; can be calculated as:
  \[ V_{aux} = \frac{V_{in,\text{min}}}{2} \cdot \frac{N_{pa}}{N_{a}} \]  
- \( N_{pa} \) is the primary to aux turn ratio; For the modified EVM \( N_{pa} = 10.4 \)
  \[ V_{aux} = \frac{85}{10.4} = 11.5V \]  
- Selecting : \( RZC_2 = 20k \)Ω and \( V_{ZCBoRise} = 0.3V \); from the electrical table of the data sheet.

Substituting all the above values to solve for \( RZC_1 \) from Equation 1 we get:

\[ RZC_1 = 750k \]Ω

\( V_{ZCBoRise} \) is used to ensure that the attenuation factor of the ZCD and Rvin divider match the attenuation factor on the original EVM.

**Ratio check for ZCD divider**

There are a number of internal voltage thresholds driven by the attenuated drain voltage signal supplied to the ZCD/CS pin.

\[ K_{ZC} = N_{pa} \cdot \frac{RZC_1}{RZC_2 + 1} \]  

Substituting the values of \( RZC_1 \) and \( RZC_2 \) from :

\[ K_{ZC} = 400.4 \]

Having this ratio (\( K_{ZC} \)) the same as the original EVM ensures that the other thresholds like Brown-out (\( V_{ZCBoRise} \)), Line feed-forward rise and fall (\( V_{FFxRise}, V_{FFxFall} \)) and the second over voltage protection (\( V_{OVP2th} \)) are still at the same levels. There is a limited scope to vary the attenuation ratio because it impacts all of these threshold values.

**RVin Divider**

The resistor divider from the rectified voltage line to ensure start-up can be calculated as:

\[ V_{in,\text{min}} \cdot \frac{RZC_2}{R_{\text{Vin}} + RZC_1 + RZC_2} = V_{ZCBoRise} \]

\( V_{ZCBoRise} \) is used to ensure that the attenuation factor of the ZCD and Rvin divider match the attenuation factor on the original EVM.

Substituting the values of \( RZC_1 \) and \( RZC_2 \) from :

\[ R_{\text{Vin}} = 7.2M \]Ω

Two resistors in series valued: 4.7MΩ and 2.7MΩ were used on the modified EVM.

**Ratio check for RVin divider**

Checking the Ratio for the attenuation divider, to make sure that matches to the original EVM. This can be done using the equation below:

\[ K_{ZC,Rvin} = \left[ \frac{R_{\text{Vin}} + RZC_1}{RZC_2} + 1 \right] \]

Substituting the values in the Equation 6 we get:

\[ K_{ZC,Rvin} = 398.5 \]

**Caux**

Caux will charge up during the TON to Vcaux, which can be defined from the equation below:

\[ V_{caux} = \frac{N_c}{N_a} \cdot V_{in} - V_{fd} \]

- \( V_{fd} \) is the forward diode voltage drop which is 0.6V

Ideally the Caux discharge should be fast enough to trace the Vaux voltage. The value of Caux voltage discharge slope when Vin is falling should be greater than the slope of Vaux. The following time constant can be used to ensure this slope.

\[ R_{ZCD} \times C_{aux} = 200\mu s \text{sec} \]

- \( RZCD \) is total resistance feeding into the ZCD pin.

\[ RZCD = RZC_1 + RZC_2 \]
Substituting the value of the selected ZCD divider resistance, we can calculate the value of the auxiliary capacitance as:

$$C_{aux} = 0.25\mu F$$  \hspace{1cm} (11)

270pF of $C_{aux}$ was selected on the modified EVM.

- **Raux**

  The value of $Raux$ and $Caux$ are chosen to ensure that the $Caux$ charging occurs very quickly cycle by cycle. Selecting the time constant during the charging period:

  $$Raux \times Caux = 100\text{nsec}$$  \hspace{1cm} (12)

  Substituting the value of $Caux$ from above, we get

  $$Raux = 400\Omega$$  \hspace{1cm} (13)

  390Ω of $Raux$ was used on the modified EVM.

- **Daux**

  It is recommended to use a diode with small reverse leakage current and forward voltage drop, a small signal diode can be a good choice. A bigger voltage drop will be replicated in the VOVP2 threshold as mentioned in a Equation 15. It is recommended to use 1N4148 or a similar diode.

### 4 Results

The section below shows comparative data between the direct drain and the aux winding approach including the waveform and the calculations supporting the difference in the results.

- **ZCD/CS waveform comparison**

  Figure 5 and Figure 6 below show the ZCD/CS waveform of the original and the modified EVM taken under 90Vac input at 100mA load condition.

  - **Brown-in Threshold**

    The Table 1 shows the brown-in threshold levels of the original EVM and the Modified EVM, the table shows that the modification does not affect this threshold.

    | Threshold Levels | Original EVM | Modified EVM |
    |------------------|--------------|--------------|
    | Brown-in threshold | 84Vac        | 83Vac        |
• **OVP2 Threshold**

UCC28056 has an OVP2 comparator with a fixed internal threshold $V_{OVP2th}$, that monitors the ZCD/CS pin voltage during the discharge time. The OVP2 threshold is 1.125V as specified in the data sheet. There is a diode drop of 0.6V from $D_{aux}$ to factor in as well.

We can calculate the value of output voltage at which the OVP2 level would trip from this information. Working backwards from the ZCD/CS pin:

\[
V_{trip} = \frac{R_{ZCD1} + R_{ZCD2}}{R_{ZCD2}} \times V_{OVP2Th}
\]

\[
V_{OVP2Th} = 1.125V : \text{known from the electrical table}
\]

\[
V_{trip} = \frac{750\text{kQ} + 20\text{kQ}}{20\text{kQ}} \times 1.125V
\]

\[
V_{trip} = 43.31V
\]  \hspace{1cm} (14)

Accounting for the diode drop we can say:

\[
V_{f1} = V_{trip} - V_d
\]

\[
V_{f1} = 43.31V - 0.6V = 42.71V
\]  \hspace{1cm} (15)

The above voltage $V_{f1}$ scaled by the turn ratio of the inductor is reflected at the output during the discharge period when the boost diode is conducting.

\[
V_{out} = N_{DA} \times V_{f1}
\]

\[
V_{out} = 10.4 \times 43.31 = 444.21V
\]  \hspace{1cm} (16)
Comparing the theoretical $V_{out}$ value to the original and the modified EVM is mentioned in the table below:

**Table 2. Over voltage protection threshold comparison**

<table>
<thead>
<tr>
<th>Threshold Levels</th>
<th>Original EVM</th>
<th>Modified EVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>OVP2</td>
<td>423V</td>
<td>443V</td>
</tr>
</tbody>
</table>

- **OCP1 Threshold**
  
The OCP1 level is a cycle-by-cycle peak current protection that terminates the $T_{on}$ duration early if the current sense to pin voltage rises above 0.5V. This is achieved by limiting the peak inductor current which avoids inductor saturation.

  This can be checked by increasing the RCS value:

  $\text{RCS}_{\text{total}} = \frac{R_9||R_{10}||R_{11}}{\text{from the original EVM}}$

  $\text{RCS}_{\text{total}} = 0.13||0.13||453k\Omega$

  $\text{RCS}_{\text{total}} = 0.065\Omega$

  (17)

  This means for 65mΩ $R_{cs}$ the normal switching operation will continue and the controller will be able to maintain the output regulation at full load condition 423mA. This also ensures the required peak inductor current does not cause the early termination of the $T_{on}$ period.

  Changing the RCS to 3.54 times the original value should cause the $T_{on}$ period to terminate early by this factor:

  \[
  I_{\text{Load}} = \frac{I_{\text{Load}}^{\text{mod}}}{3.54}
  \]

  \[
  I_{\text{Load}}^{\text{mod}} = 120mA
  \]

  (18)

  The Table 3 shows the OCP1 threshold comparison of the Original and the modified EVM a resistor value of 230mΩ was selected for the $R_{cs}$.

**Table 3. Over current protection threshold comparison**

<table>
<thead>
<tr>
<th>Threshold Levels</th>
<th>Original EVM</th>
<th>Modified EVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCP1</td>
<td>140mA Load</td>
<td>130mA Load</td>
</tr>
</tbody>
</table>

- **Stand-by Power comparison**
  
  These calculations show the contribution of the aux winding approach to the total standby power measurements. The electronic load has been disconnected for this test. The average input power is measured across the input and external VCC over a 10 min interval.

  \[
  P_{\text{stby}} = \frac{V_{\text{in}}^2}{R}
  \]

  - $V_{\text{in}}$ is the peak of line bulk voltage.
  - $R$ is the total resistance in the impedance path.

  (19)

  \[
  P_{\text{stby}} = \frac{(265/2)^2}{R_{\text{in}} + R_{ZCD1} + R_{ZCD2}}
  \]

  \[
  P_{\text{stby}} = \frac{7.2M + 750k + 20k}{265/2}
  \]

  \[
  P_{\text{stby}} = 17.6\text{mW}
  \]

  (20)

  The Table 4 contains the modified EVM standby power measurements:

**Table 4. Total Standby Power**

<table>
<thead>
<tr>
<th>Input Voltage (Vrms)</th>
<th>Input Power (mW)</th>
<th>Vcc Voltage (V)</th>
<th>Vcc Current (µA)</th>
<th>Total Standby Power: Modified EVM (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>27.36</td>
<td>12.01</td>
<td>102.89</td>
<td>28.596</td>
</tr>
<tr>
<td>115</td>
<td>28.44</td>
<td>12.01</td>
<td>102.98</td>
<td>29.677</td>
</tr>
<tr>
<td>230</td>
<td>64.7</td>
<td>12.01</td>
<td>103.12</td>
<td>65.938</td>
</tr>
<tr>
<td>265</td>
<td>69.52</td>
<td>12.01</td>
<td>103.5</td>
<td>70.763</td>
</tr>
</tbody>
</table>
The Figure 8 shows the comparative difference in the standby power between the original and the modified EVM.

![Figure 8. Standby power comparison](image)

**Start-up**

The Figure 9 through Figure 16 show the output voltage behavior when the line voltage has already been applied and the instant the VCC voltage exceeds the startup threshold on the EVM with the new approach, where CH1- Vout, CH4- Vin_AC and CH3- Vcc.

![Figure 9. 85Vinac @ NL](image)

![Figure 10. 85Vinac @ FL](image)
• Valley Switching
  The Figure 17 through Figure 20 shows drain to source voltage of the MOSFET and the valley switching action on the EVM with the modified EVM.
Figure 17. 85Vinac @ 60mA Load
Figure 18. 115Vinac @ 60mA Load
Figure 19. 230Vinac @ 100mA Load
Figure 20. 265Vinac @ 100mA Load

- **Transient Response**
  The Figure 21 and Figure 22 shows the transient response of the EVM with the aux winding approach, where CH1: Vout and CH4: Iout
Figure 21. No-Load to 200mA @ 90Vac
Figure 22. No-Load to 400mA @ 90Vac

- **Line Voltage and Line Current**
  The Figure 23 and Figure 24 illustrates the low-line and high-line voltage and current waveforms, where CH4: Vinac and CH2: Iinac
Figure 23. Low-line Voltage and Current waveforms
5 Layout Guidelines

The ZCD/CS resistor network is very sensitive to parasitic capacitance, which can be present between RZCD1 or RZCD2 resistor nodes and the surrounding high voltage switching nodes. The presence of this parasitic capacitance can cause false fault detection triggering of OCP2 and OVP2 causing the controller to shutdown and operate in hiccup mode with an interval of 1sec attempting to turn-ON.

- RZCD2 must be placed as close as possible to ZCD/CS Pin on the controller.
- Rvin and RZCD1 must be placed as close as possible to the RZCD2 resistor.
- PCB traces connecting RZCD1 and Rvin should be kept as short as possible; the width of these traces should be very narrow to allow for the minimum parasitic capacitance.
- The traces connecting the high valued resistors feeding to the ZCD/CS pin, DRV pin, Vrect should be at least 1cm apart to avoid coupling.
- It is important to keep the traces feeding the ZCD/CS pin as far as possible to the high switching traces eg. VDrain.

The Figure 25 shows an example layout of the modified EVM bottom layer with highlighted circuit.

Figure 24. High-Line Voltage and Current waveform
Please refer to the schematic below to identify the modified circuit elements. Figure 26 is a updated schematic diagram with the proposed approach.

Figure 26. Modified EVM schematic
## Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

<table>
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<th>Changes from Original (October 2018) to A Revision</th>
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<td>• Changed Text modified</td>
<td>1</td>
</tr>
<tr>
<td>• Changed Text modified and margins adjusted</td>
<td>3</td>
</tr>
<tr>
<td>• Changed Text modified</td>
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