ABSTRACT

The UCC28700 device is a primary controlled fly-back power supply controller, which provides both constant voltage and constant current regulation. The device has high resolution for voltage and current regulation, and it has very low no-load power consumption and good start-up performance. As a result, the UCC28700 device is highly suited for low-power adapter and auxiliary power supply application. Compared with other competitors, the UCC28700 device has better performance and needs a smaller $V_{DD}$ capacitor. A customer may experience a situation in which the UCC28700 device cannot start a constant current full load, but can start at resistance full load. The real reason is that the value of the $V_{DD}$ capacitor is not sufficient and primary peak current is designed too small. This paper analyzes the design of primary peak current and $V_{DD}$ capacitor. An experiment result validates the theoretical analysis.

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1. Introduction

The UCC28700 device is a constant voltage, constant current fly-back controller with primary side regulation without the use of an optical coupler. Figure 1 shows the UCC28700 application circuit.

![UCC28700 Application Circuit](image)

In Figure 1:
- **R\text{STR}** is high-voltage start-up resistance.
- **C\text{DD}** is energy storage capacitor on the V\text{DD} pin.
- **R\text{S1}** is high-side feedback resistance.
- **R\text{S2}** is low-side feedback resistance.
- **R\text{CBC}** is programming cable compensation resistance.
- **R\text{CS}** is primary peak current programming resistance.
- **R\text{LC}** is MOSFET turn-off delay compensation programming resistance.

Primary peak current is a critical factor for the UCC28700 starting up at constant current full load. The following section provides a detailed analysis.

2. Analysis

Figure 2 shows the UCC28700 secondary side circuit, \( I_s = I_c + I_L \). If the load of the UCC28700 device is resistance at the beginning of startup, \( V_o \) ramps up from zero and \( I_L \) is low enough so that high \( I_s \) is not required. However, if the load of the device is constant current and the load current is large, high \( I_s \) is required to make \( I_L \) positive and to reduce the time that output voltage ramps up from 0 to \( V_{\text{OCC}} \). \( V_{\text{OCC}} \) is the target lowest converter output voltage, which makes auxiliary turn voltage equal to UVLO turn-off voltage on the V\text{DD} pin.
To C\(_{\text{DD}}\), C\(_{\text{O}}\), and the transformer, the following equations are achieved. In Equation 4, a 1-mA current margin is provided.

**NOTE:** N\(_{\text{P}}\) is primary turns of transformer, N\(_{\text{S}}\) is secondary turns, and N\(_{\text{A}}\) is auxiliary turns.

\[
I_{\text{C}} = I_{\text{S}} - I_{\text{L}} \tag{1}
\]

\[
V_{\text{OCC}} = V_{\text{DD(off)}} \frac{N_{\text{S}}}{N_{\text{A}}} \tag{2}
\]

\[
t_{\text{a}} = C_{\text{O}} \frac{V_{\text{OCC}}}{I_{\text{C}}} \tag{3}
\]

\[
\Delta V_{\text{DD}} = \frac{(I_{\text{run}} + 1\text{mA})}{C_{\text{DD}}} t_{\text{a}} \tag{4}
\]

\[
V_{\text{DD}} = V_{\text{DD(on)}} - \Delta V_{\text{DD}} \tag{5}
\]

Where:

- V\(_{\text{DD(off)}}\) is UVLO turn-off voltage.
- V\(_{\text{DD(on)}}\) is UVLO turn-on voltage.
- I\(_{\text{run}}\) is supply current on the V\(_{\text{DD}}\) pin when UCC28700 works.
- V\(_{\text{DD}}\) is the voltage of C\(_{\text{DD}}\).
- \(\Delta V_{\text{DD}}\) is the decreased voltage on C\(_{\text{DD}}\).
- t\(_{\text{a}}\) is the time that output voltage ramps up from 0 to V\(_{\text{OCC}}\).

According to the preceding equations, if the value of I\(_{\text{S}}\) is low, I\(_{\text{C}}\) will be small, so t\(_{\text{a}}\) becomes a long time when output voltage ramps up to V\(_{\text{OCC}}\); however, during this period, V\(_{\text{DD}}\) may decrease below V\(_{\text{DD(off)}}\) and the UCC28700 device may enter UVLO state and stop switching. Then the current through R\(_{\text{STR}}\) charges C\(_{\text{DD}}\); when V\(_{\text{DD}}\) is higher than V\(_{\text{DD(on)}}\), the device restarts. Although faulty startup continues, the UCC28700 device cannot enter normal state.

In Equation 4, if C\(_{\text{DD}}\) is large enough, \(\Delta V_{\text{DD}}\) will be small for certain t\(_{\text{a}}\). So, both a large value C\(_{\text{DD}}\) and a high primary peak current can make the UCC28700 device start well. However, large value C\(_{\text{DD}}\) means higher price and larger size, and high primary peak current increases power loss and increases transformer size. Consequently, choosing C\(_{\text{DD}}\) and primary peak current is a trade-off.
In normal operation, auxiliary winding voltage dominates $V_{DD}$. If $V_O$ reaches its maximum value, $V_{DD}$ will also match its maximum value. The relation is shown in Equation 6.

$$V_{DD\text{max}} = V_{O\text{max}} \frac{N_A}{N_S}$$

(6)

From Equation 2, 3, and 6, if $N_A$ increases, $t_a$ is reduced, that’s good for UCC28700 starting up. So a large value should be chosen for $N_A$, and it also must provide voltage margin for $V_{DD}$.

3. Design

All device values, except $C_{DD}$ and $R_{CS}$, are the same as the UCC28700EVM-068 5-W USB adapter [1] schematic. Figure 3 is shown in the UCC28700 data sheet [2]. $I_S$ is deduced as Equation 7, where $\eta_{XFMR}$ is estimated transformer efficiency.

Transformer efficiency is influenced by the core and winding losses, leakage inductance ratio, and bias power ratio to rated output power. For a 5-V, 1-A charger example, bias power of 1.5% is a good estimate [1]. An overall transformer efficiency of 0.9 is an approximate estimate to include 3.5% leakage inductance, 5% core and winding loss, and 1.5% bias power [1].

Maximum primary peak current $I_{PP}$ is achieved at the beginning of startup, and the UCC28700 device enters constant current regulation with maintaining constant secondary diode conduction duty cycle, 0.425.

The transformer is WE 750312723 on EVM, $N_p/N_S = 15.33$, $N_p/N_A = 3.83$, and saturation current is 440 mA.

$$I_S = \frac{I_{PP} N_p t_{DM}}{2 N_S T_{SW}} \eta_{XFMR}$$

(7)

Figure 3. Transformer Current
At the beginning of startup, average charging current of output capacitor is positive, the charge current equals \((I_S-I_L)\) as Equation 1 shows. Before \(V_O\) ramps up to \(V_{OCC}\), the auxiliary turn voltage is lower than \(V_{DD}\), and \(C_{DD}\) cannot be charged by auxiliary turns. However, \(C_{DD}\) is discharged by \(I_{run}\) and gate drive current during this period; if \(V_{DD}\) is lower than \(V_{DD(off)}\), the UCC28700 device shuts down. To ensure the device starts up well, \(V_{DD}\) must be larger than \(V_{DD(off)}\) during \(t_s\). In Equations 8 and 9, a critical condition is applied; \(t_{start}\) is the time that \(V_O\) ramps up from 0 to \(V_{OCC}\). Equation 2 shows the relation of \(V_{OCC}\) and \(V_{DD(off)}\). An estimated 1 mA of gate-drive current exists in Equation 8 and 1 V of margin is added to \(V_{DD}\). \(V_{CST}\) is chip select threshold voltage. At the beginning of startup, voltage on the UCC28700 VS pin is low, so \(V_{CST}\) stays at its maximum value.

\[
C_{DD} = \frac{t_{start}(I_{run} + 1mA)}{(V_{DD(on)} - V_{DD(off)}) - 1V} \quad (8)
\]

\[
t_{start} = \frac{C_{DD}V_{OCC}}{I_S - I_L} \quad (9)
\]

\[
R_{CS} = \frac{V_{CST}}{I_{PP}} \quad (10)
\]

In the UCC28700 device, \(V_{DD(on)} = 21\) V, \(V_{DD(off)} = 8.1\) V, so according to Equation 2, \(V_{OCC} = 2.02\) V. \(I_{run} = 2.1\) mA in data sheet, \(C_{DD}\) is chosen as 4.7 \(\mu\)F, \(t_{start} = 18.04\) ms is deduced by Equation 8. UCC28700 EVM is 5-V, 1-A adapter, so full load current \(I_L\) is 1 A. Output capacitors are two paralleled 560-\(\mu\)F capacitors, so \(C_O = 1120\) \(\mu\)F. \(t_{start}\), \(I_L\), and \(C_O\) are substituted into Equations 7 and 9, \(I_{PP}\) is obtained as 383.85 mA. From Equation 10, \(R_{CS} = 1.95\) \(\Omega\). To add margin on \(V_{DD}\), 1.8 \(\Omega\) is selected for \(R_{CS}\).

As shown in Table 1, the UCC28700 device has better constant current (CC) regulation performance; a higher max operation frequency, which can minimize the solution size; standby power is less than 30 mW, which is for 5-star rating; and higher max \(V_{DD}\), which can reduce \(V_{DD}\) capacitor value. Of the three products highlighted in Table 1, the UCC28700 device is the best choice when designing 5-V adapters. The UCC28700 device can choose higher \(N_A/N_B\) because it has higher max \(V_{DD}\) according to Equation 2, and smaller \(t_{start}\) is achieved (see Equation 9). In Equation 8, \(t_{start}\) is proportional to \(C_{DD}\), so smaller \(C_{DD}\) is required during design.
Table 1. Parameters Comparison Table

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<th>iW1680</th>
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<td>CV (constant voltage)</td>
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<td>5%</td>
<td>null</td>
</tr>
<tr>
<td>CC (constant current)</td>
<td>5%</td>
<td>6%</td>
<td>null</td>
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<tr>
<td>Max Operation Frequency</td>
<td>130 kHz</td>
<td>100 kHz</td>
<td>72 kHz</td>
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<tr>
<td>Standby Power</td>
<td>&lt;30 mW</td>
<td>&lt;200 mW</td>
<td>&lt;30 mW</td>
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<td>Max V\textsubscript{DD}</td>
<td>38 V</td>
<td>28 V</td>
<td>25 V</td>
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</table>

4. Experiment

To validate the preceding analysis, a UCC28700EVM-068 5-W USB adapter is used. All device values are kept the same except C\textsubscript{DD} and R\textsubscript{CS}, C\textsubscript{DD} = 4.7 µF, R\textsubscript{CS} = 1.8 Ω. The load is constant current as 1 A.

Figure 4 is a UCC28700 start-up waveform. CH1 is a MOSFET gate-drive signal and CH3 is output voltage. The device starts up smoothly, with no overshoot and audible noise. The figure shows the UCC28700 device has a very good start-up performance. In Figure 4, t\textsubscript{start} approximates 18 ms, which meets the calculated result.

![Figure 4. UCC28700 Start-up Waveform](image)

Figure 5, Figure 6, and Figure 7 represent a compared experiment. CH1 is V\textsubscript{DD} voltage and CH3 is output voltage.
• In Figure 5, $C_{DD} = 4.7 \, \mu F$, $R_{CS} = 2.05 \, \Omega$: because primary peak current is not large enough, $V_{DD}$ decreases below $V_{DD(\text{off})}$, thus the UCC28700 device cannot start.

• In Figure 6, $C_{DD} = 4.7 \, \mu F$, $R_{CS} = 1.8 \, \Omega$: primary peak current is increased, so a good start-up performance is observed.

• In Figure 7, $C_{DD} = 1 \, \mu F$, $R_{CS} = 1.8 \, \Omega$: the UCC28700 device cannot start because $C_{DD}$ is not large enough to provide sufficient energy.

The results of the experiment reveal that both high primary peak current and large volume $C_{DD}$ can make the UCC28700 device start successfully at constant current full load. These findings verify the preceding analysis.
5. Conclusion

Comparison results indicate the UCC28700 device has better performance in CV and CC regulation, solution size, standby power, and $V_{DD}$ capacitor value. In the course of this study, primary peak current and $V_{DD}$ capacitor were analyzed and calculated. Proper parameters were chosen according to equations, and the analysis was verified by experiment results.

6. References


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