Analysis of Start-Up Performance for UCC28700

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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.

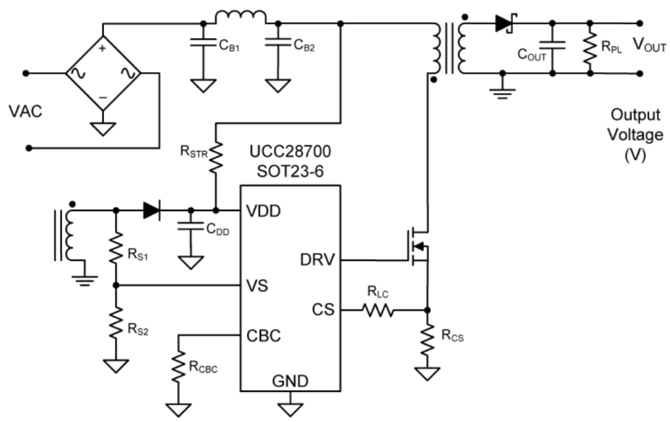

Figure 1. UCC28700 Application Circuit

In Figure 1:

- R_{STR} is high-voltage start-up resistance.
- C_{DD} is energy storage capacitor on the V_{DD} pin.
- R_{S1} is high-side feedback resistance.
- R_{S2} is low-side feedback resistance.
- R_{CBC} is programming cable compensation resistance.
- R_{CS} is primary peak current programming resistance.
- R_{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_C positive and to reduce the time that output voltage ramps up from 0 to V_{OCC}. V_{OCC} is the target lowest converter output voltage, which makes auxiliary turn voltage equal to UVLO turn-off voltage on the V_{DD} pin.

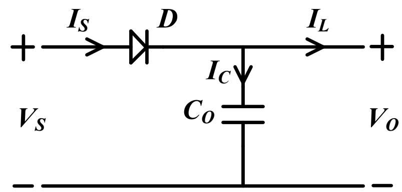

Figure 2. UCC28700 Secondary Side Circuit

To C_{DD}, C_O, and the transformer, the following equations are achieved. In Equation 4, a 1-mA current margin is provided.

NOTE: N_P is primary turns of transformer, N_S is secondary turns, and N_A is auxiliary turns.

$$I_C = I_S - I_L \quad (1)$$

$$V_{OCC} = V_{DD(off)} \frac{N_S}{N_A} \quad (2)$$

$$t_a = C_O \frac{V_{OCC}}{I_C} \quad (3)$$

$$\Delta V_{DD} = \frac{(I_{run} + 1mA)}{C_{DD}} t_a \quad (4)$$

$$V_{DD} = V_{DD(on)} - \Delta V_{DD} \quad (5)$$

Where:

- $V_{DD(off)}$ is UVLO turn-off voltage.
- $V_{DD(on)}$ is UVLO turn-on voltage.
- I_{run} is supply current on the V_{DD} pin when UCC28700 works.
- V_{DD} is the voltage of $C_{DD.}$
- ΔV_{DD} is the decreased voltage on C_{DD}.
- t_a is the time that output voltage ramps up from 0 to V_{OCC}.

According to the preceding equations, if the value of I_S is low, I_C will be small, so t_a becomes a long time when output voltage ramps up to V_{OCC}; however, during this period, V_{DD} may decrease below $V_{DD(off)}$ and the UCC28700 device may enter UVLO state and stop switching. Then the current through R_{STR} charges C_{DD}; when V_{DD} is higher than $V_{DD(on)}$, the device restarts. Although faulty startup continues, the UCC28700 device cannot enter normal state.

In Equation 4, if C_{DD} is large enough, ΔV_{DD} will be small for certain t_a. So, both a large value C_{DD} and a high primary peak current can make the UCC28700 device start well. However, large value C_{DD} means higher price and larger size, and high primary peak current increases power loss and increases transformer size. Consequently, choosing C_{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.

$$V_{DD\max} = V_{O\max} \frac{N_A}{N_S} \tag{6}$$

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 η_{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.

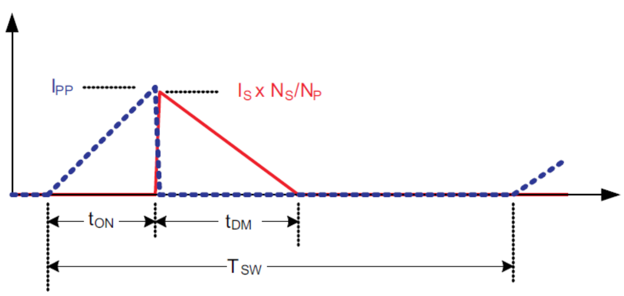

Figure 3. Transformer Current

$$I_S = \frac{I_{PP} N_P t_{DM}}{2 N_S T_{SW}} \eta_{XFMR} \tag{7}$$

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_a. 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.

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

$$t_{start} = \frac{C_O V_{OCC}}{I_S - I_L} \tag{9}$$

$$R_{CS} = \frac{V_{CST}}{I_{PP}} \tag{10}$$

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 µF, 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-µF capacitors, so C_O = 1120 µF. 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 Ω. To add margin on V_{DD}, 1.8 Ω 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_S 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

Product Number	UCC28700	OB2520M	iW1680
CV (constant voltage)	5%	5%	null
CC (constant current)	5%	6%	null
Max Operation Frequency	130 kHz	100 kHz	72 kHz
Standby Power	<30 mW	<200 mW	<30 mW
Max V_{DD}	38 V	28 V	25 V

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_{DD} and R_{CS}, C_{DD} = 4.7 µF, R_{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_{start} approximates 18 ms, which meets the calculated result.

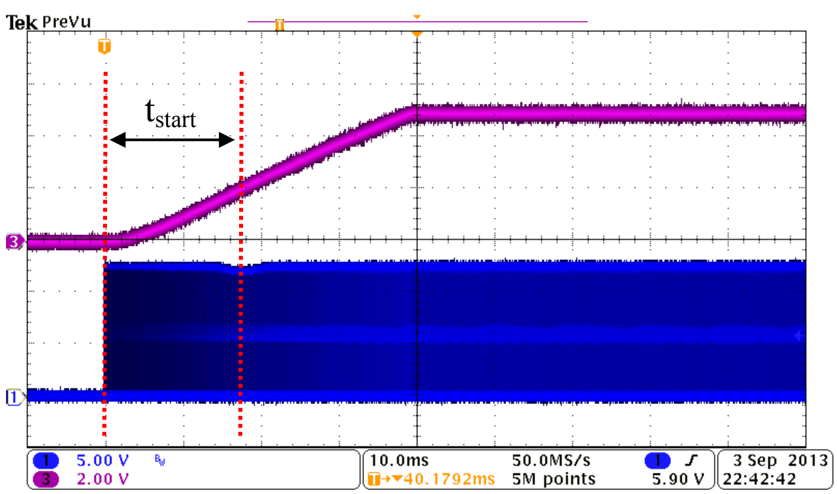

Figure 4. UCC28700 Start-up Waveform

Figure 5, Figure 6, and Figure 7 represent a compared experiment. CH1 is V_{DD} voltage and CH3 is output voltage.

- In Figure 5, C_{DD} = 4.7 µF, $R_{C\,S}$= 2.05 Ω: because primary peak current is not large enough, V_{DD} decreases below $V_{DD(off)}$, thus the UCC28700 device cannot start.
- In Figure 6, C_{DD} = 4.7 µF, R_{CS} = 1.8 Ω: primary peak current is increased, so a good start-up performance is observed.
- In Figure 7, C_{DD} = 1 µF, R_{CS} = 1.8 Ω: 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.

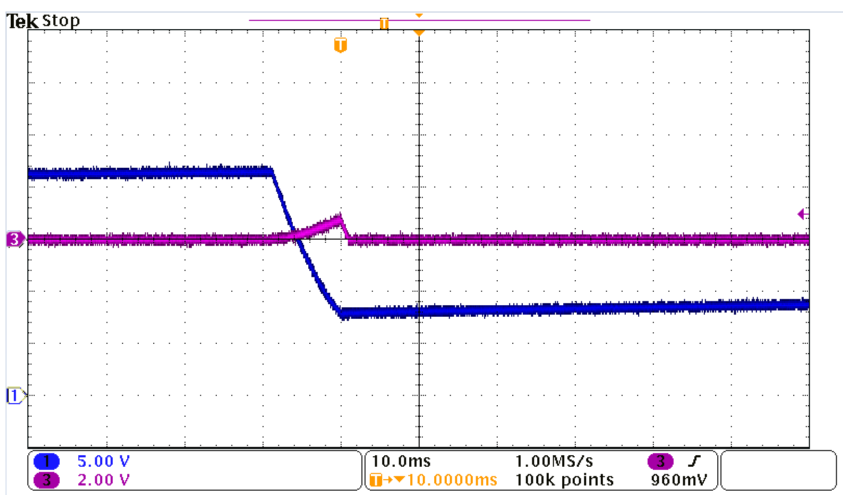

Figure 5. UCC28700 Start-up Waveform with C_{DD} = 4.7 µF, R_{CS} = 2.05 Ω

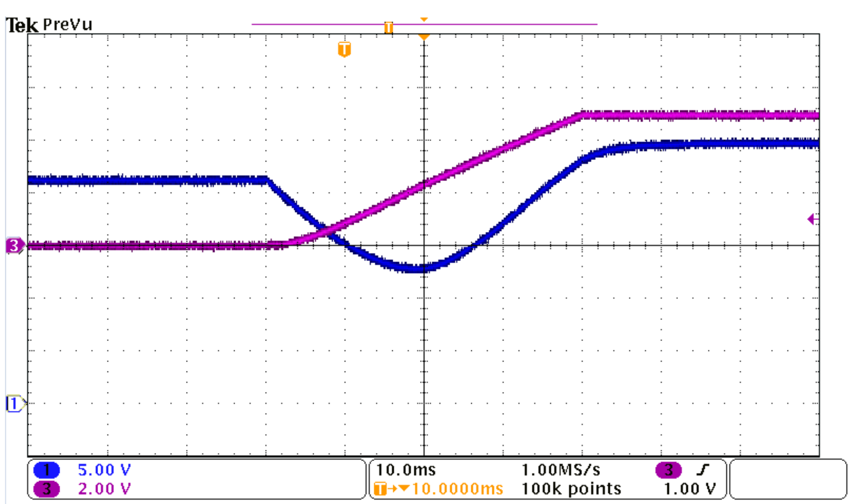

Figure 6. UCC28700 Start-up Waveform with C_{DD} = 4.7 µF, R_{CS} = 1.8 Ω

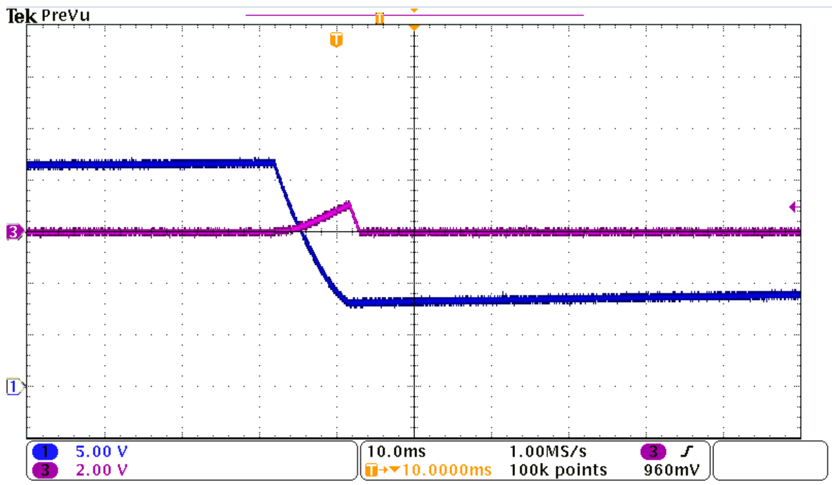

Figure 7. UCC28700 Start-up Waveform with C_{DD} = 1 μF, R_{CS} = 1.8 Ω

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

[1] *UCC28700EVM-068 5-W USB Adapter*. Texas Instruments User's Guide, SLUU968, July 2012

[2] *Constant-Voltage, Constant-Current Controller With Primary-Side Regulation*. Texas Instruments UCC2870x data sheet, SLUSB41, July 2012

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