1.5 MHz, 300 mA Step-Down Switching Regulator

Dongsuk Lee, Hyunseok Nam, Youngkook Ahn and Jeongjin Roh
Department of Electrical Engineering, Hanyang University
Ansan, Korea
jroh@hanyang.ac.kr

Abstract— A switching regulator yields high efficiency and provides a good current driving capability, making it appropriate as a DC-DC converter for mobile devices. The battery voltage can be converted into the operating voltage of the internal circuit. Furthermore, a negative feedback loop can be constructed to restrict change in dc voltage for a stable supply. A current-mode switching regulator adjusts the inductor current to stabilize the output voltage. The designed 1.5 MHz 300 mA step-down switching regulator is implemented in a standard 0.18-µm CMOS process.

Keywords - DC-DC converter, power management, switching regulator, buck converter, current-mode

I. INTRODUCTION

A DC-DC converter can be used to convert a given dc voltage into a desired dc voltage. Types of DC-DC converter include linear regulator, charge pump and switching regulator. A switching regulator turns the switch on and off to deliver energy. Components for maintaining current (inductor) and voltage (capacitor) are used simultaneously to transfer average voltage. A switching regulator provides excellent efficiency and a good current driving capability. With the convergence of mobile devices and multimedia functions that require a lot of data, the switching regulator is increasingly important because of its ability to use limited battery capacity efficiently [1].

II. ANALYSIS AND DESIGN

Since a switching regulator outputs average voltage through an LC filter, there is some ripple in the inductor current and the output voltage. In Fig. 1, since the voltages at the SW node and across the inductor are 0 V and V_{out} respectively, when the NMOS power transistor is on,

\[ V_L = -V_{out} = L \frac{di_L}{dt} \]  

where \( V_L \) is the inductor voltage, \( V_{out} \) is the output voltage, \( L \) is inductance, \( i_L \) is the inductor current. The inductor current ripple \( \Delta i_L \) can be expressed as

\[ \Delta i_L = \frac{V_{out}(1 - D)T_s}{2L} \]  

where \( D \) is the duty, \( T_s \) is the period. When the inductor current is greater than the output current, the residual charge \( \Delta Q \) is

\[ \Delta Q = \frac{1}{2} \frac{T_s}{2} \Delta i_L \]  

Substituting (2) into (3),

\[ \Delta Q = \frac{1}{2} \frac{T_s}{2} \frac{V_{out}(1 - D)T_s}{2L} = \frac{V_{out}(1 - D)T_s^2}{8L} \]  

If \( \Delta Q \) charges the capacitor \( C \), the output voltage ripple \( \Delta V_{out} \) becomes

\[ \Delta V_{out} = \frac{\Delta Q}{C} = \frac{V_{out}(1 - D)T_s^2}{8LC} \]  

Accordingly, inductance \( L \) and capacitance \( C \) can be controlled to adjust the ripples in the inductor current and the output voltage. Since the average voltage across the inductor for a single period is 0 V,

\[ (V_{in} - V_{out})DT_s = V_{out}(1 - D)T_s \]  

where duty \( D \) is

\[ D = \frac{V_{out}}{V_{in}} \]  

here, the duty is the ratio of the duration for which the PMOS power transistor is turned on in one period. By turning the PMOS power transistor on and off periodically with the duty of (7), the input dc voltage can be converted into the desired dc voltage [3].

A negative feedback loop can be constructed as shown in Fig. 1 to restrain change in the converted output dc voltage and supply a stable dc voltage. In Fig. 1, if the output voltage increases past the reference voltage \( V_{ref} \), the reference current \( I_{ref} \) and the average inductor current decrease, reducing the output voltage. If the output voltage decreases below \( V_{ref} \), the reference current \( I_{ref} \) and the average inductor current increase, elevating the output voltage. Adjusting the average inductor current to stabilize the output voltage is referred to as a current-mode switching regulator [3].

Directly comparing the inductor current and the reference current \( I_{ref} \) however, the inductor current can oscillate if the duty is 0.5 or higher. Therefore, in actual implementation, the
The inductor current of the current sensor and the ramp signal of the ramp generator are added and compared with the reference current $I_{ref}$, as shown in Fig. 1, to prevent the inductor current from oscillation [3].

A switching regulator must include compensation to widen the bandwidth, reduce the response time, and decrease the gain at the switching frequency so that the effects of switching noise can be minimized. It is easier to compensate for the current-mode switching regulator because there are two poles in the voltage-mode, but there is only one pole in the current-mode system [2].

III. CHIP IMPLEMENTATION

The step-down switching regulator of this study was fabricated with the standard 0.18-$\mu$m CMOS process. Fig. 2 displays the layout of the chip, the size of which is 1.05 mm$^2$ (1.05 mm × 1.00 mm).

Fig. 3 displays the test waveform of the output voltage when the output current is changed instantaneously (with $V_{in}=2.85$ V, $V_{out}=1$ V, $L=6.8$ $\mu$H and $C=4.7$ $\mu$F). When the output current was changed from 300 mA $\rightarrow$ 100 mA $\rightarrow$ 300 mA, the output voltage changes for a brief moment and returns to the original level. It can be confirmed that change in the output voltage is restrained and a stable output voltage is maintained.

Table I summarizes the performance of step-down switching regulator implemented in this paper.

IV. CONCLUSION

This paper described the process of designing a 1.5 MHz, 300 mA step-down switching regulator. The step-down switching regulator was manufactured with the standard 0.18-$\mu$m CMOS process, and the chip size is 1.05 mm$^2$. Measurements indicate that the regulator operates at the frequency of 1.5 MHz, input voltage of 2.5-3.3 V, output voltage of 0.8-3.3 V, and output current of 0-300 mA. The implemented step-down switching regulator supplied a stable dc voltage with a maximum efficiency of 80%.

ACKNOWLEDGMENT

This work was supported by the IC Design Education Center (IDEC).

REFERENCES


