Multi-mode High-efficiency PWM AC/DC Controller Design

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Abstract. This paper proposes a multi-mode pulse-width modulation (PWM) AC/DC controller, which was implemented on a 40-V 0.8-µm one-poly two-metal (1P2M) CMOS process. It can change the operation mode by using an inner logic controller to improve the conversion efficiency under all load conditions. The necessary protection circuits are integrated on chip to reduce the number and size of the discrete components. The area of the chip is as small as 1410 X 730 µm². The standby power is lower than 100mW, and the conversion efficiency is higher than 85%. Test results have met the most stringent power consumption standards of “Energy Star VI”. The Design has achieved the industrial mass production, used in portable electronic device adapter.

Introduction

Power supply is the power support of the electronic equipment in modern communication, aerospace, biotechnology and other high-tech fields. Switching power supply and linear power supply are the two main technologies of the modern electronic power supply, in which the switching power supply is characterized by lower power consumption, higher efficiency, smaller volume and lighter weight, etc. The average efficiency of the PWM switching power supply is usually up to 65~70%. However, with the increasingly market demand of the portable electronic devices, 70% conversion efficiency is not enough. In July 2013, the Department of Energy (DoE) pushed "the requirements of external power adaptors" to "Energy Star VI standards", as shown in table 1.

| Average efficiency | Standby power [mW] |
|--------------------|--------------------|
| ≥ 85.00%           | < 100              |

This work recommends a high-performance PWM AC/DC controller using multi-mode quasi-resonant technology according to the Energy Star VI standard, which is implemented on a 40-V 0.8-µm 1P2M CMOS process [1]. It has been proved that the chip is smaller and costs lower than the mainstream products at home and abroad. Moreover, this design has been mass produced on an industrial scale utilized in power adapters of portable electronic devices.

In Section 1, the proposed high-efficiency AC/DC voltage controller is illustrated. Section 2 introduces the test results obtained for the overall chip, while Section 3 concludes by explaining how the application of the proposed AC/DC controller meets the Energy Star VI standard.

Controller Chip Design

Key Technologies of High-efficiency Switching Power Supply

The modulation modes of switching power supply include pulse width modulation (PWM), pulse frequency modulation (PFM) and hybrid mode (PWM/PFM), in which the PWM mode is the most
widely used control mode. The traditional PWM is composed of reference voltage, comparator, error amplifier, oscillator and other modules, and is also the foundation of the AC/DC controller. The in-depth theory can be referred in reference [2].

There are three points about the key technologies of high-efficiency PWM AC/DC voltage controller. The first is to use the logic controller to control the working mode of PWM modulation under different loads, which can overcome the disadvantages of low efficiency of PWM in light load or no-load. Secondly, the switching loss of switching power supply is reduced by using the quasi-resonant technology. Thirdly, under high supply voltage, the working voltage of core circuit is reduced by the built-in low dropout (LDO), which reduces the power consumption of the entire system to a great extent. This paper introduces the first point in this design.

The common working modes are named as continuous current mode (CCM), discontinuous current mode (DCM), critical conduction mode (CRM) and Burst [3]. Under full load, PWM modulator usually works in CCM mode which is the optimization one due to the lower noise and higher efficiency. On the contrary, under light load or no load, if the switch operating frequency is changeless, the switching loss will be accounted for most of the system power consumption, resulting in lower system efficiency. The multi-mode modulating adopted in this design is a commendable method to solve this problem. The circuit can follow the load variation and adjust the working mode, which has a great relationship with the switching frequency. Multi-mode modulation greatly improves the efficiency under all kinds of load conditions.

Overview of the Chip Structure

Figure 1 is the overall frame diagram of the proposed AC/DC controller chip. The recommended range of input supply voltage is 9-30 V. It is defined to drive an external power metal-oxide-semiconductor field-effect transistor (MOSFET), whose drain voltage can be as high as 650 V. Another key module is the logic controller, which can control the frequency of the internal oscillator according to the feedback value, in order to achieve high-efficiency conversion under different loads [4]. It also integrated more functions to reduce the discrete components’ quantity and size, such as under-voltage lockout (UVLO) [5], leading-edge blanking (LEB), over-voltage protection (OVP), under-voltage protection (UVP) and open Loop protection (OLP). Their

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2
relationships are simply illustrated in figure 1. All kinds of these protections are used to prevent the circuit from being damaged due to the abnormal conditions. In addition, an on-chip 5-V low dropout (LDO), which powers the major blocks of the AC/DC controller, is also integrated. Furthermore, it has been proven that the controller is an ideal design for low-cost applications.

**Multi-mode PWM Modulation**

![Flyback topology](image_url)

Figure 2. Flyback topology.

Figure 2 is the recommended flyback topology circuit, which is the application circuit designed for system simulation and testing [6]. The multi-mode quasi-resonant PWM AC/DC conversion introduced in this paper can be perfectly implemented through this topology.

In figure 2, U1 is the integrated circuit (IC) we designed which is used to drive the power MOSFET M1. There are also several precise references voltages produced in U1. The feedback voltage vfb is affected by the change of the load current through an optocoupler U2. Comparing the vfb and these references step by step, the inner logical controller adjusts the duty ratio of the output GATE to accommodate the load current. The inner logic controller changes the working mode according to the switching frequency and vfb voltage.

![Multi-mode PWM](image_url)

Figure 3. Multi-mode PWM.

The detailed multi-mode scheme is illustrated in figure 3. At the normal operating condition, the U1 operates in CRM mode to reduce the switching loss. By this time, the frequency varies depending on the supply AC voltage (vinac in figure 2) and the load conditions. As the output load current is increased, the on-time of M1 is increased too, and thus the switching frequency decreases. When the switching frequency becomes lower than 100 kHz, the controller spontaneously transits to a CCM mode. As the output load current is decreased, the on-time of M1 is decreased too, and thus the switching frequency increases. At light load conditional, the vfb is lower and the system operates in the green mode for high-efficiency conversion. The switching frequency will start to linearly decrease from 106 kHz to 23 kHz. At zero load or very light load conditions, the output pin GATE of U1 will be disabled immediately under such condition, enhancing power saving. Figure 4 shows the simulation results of vfb and the drain current of M1 at no-load condition and full-load condition.
Chip Layout

The design implemented on a 40-V 0.8-μm 1P2M CMOS process. The chip area only occupies 1410 X 730 um$^2$, and the micrograph is in figure 5.

Test Results

Figure 6 (a) demonstrates the relationship between the switching frequency and the load current. When the AC supply is fixed, the variation trend of switching frequency is as same as that of the load current. At light-load conditions, the lower switching frequency can save power effectively.

Figure 6 (b) exhibits the relationship between the standby power and the AC supply. Furthermore, a commercially available switching power supply product named GR9230 is utilized to compare with this work, which has similar energy efficiency and similar applications. It can be observed that the higher the AC supply is, the higher the standby power is. On the whole, the standby powers of both designs are lower than 100 mW under all conditions, and the standby power of this work is lower than that of GR9230. Furthermore, it has been proved that the conversion efficiencies of both designs are higher than 85% and meet the Energy Star VI standard. However, the design of GR9230 is based on a 1P3M process, which has an additional mask layer. In addition, the controller chip area of GR9230 is 1.5 mm$^2$, while the area of the proposed system is only 1 mm$^2$. Compared to GR9230, this work performs better and has a lower cost in practical applications.
Conclusion

In this paper, a multi-mode high-performance PWM AC/DC controller is presented, which can drive a 650-V power MOSFET according to the Energy Star VI standard in typical applications of AC/DC adapters in portable electronic devices. This work is based on a 40-V 0.8-µm 1P2M CMOS technology. The chip area only occupies 1410x730 µm². The standby power is lower than 100mW and the conversion efficiency is higher than 85%. Furthermore, the controller can be applied in quick-charge applications, which are the most advanced power adapters in the market. The controller has been mass produced on an industrial scale.

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