Optimal Design of SWITCHING POWER SUPPLY

Zhanyou Sha • Xiaojun Wang
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Preface

In recent years, the rapid development of modern power technology and the huge demand of the global market have resulted in higher requirements for the optimal design of switching-mode power supply (SMPS). The so-called optimal design refers to selecting the best design from a variety of design schemes. It should be pointed out that the optimal design is always relative, not absolute. Optimal design is not necessarily the one and only, and there may be several options for designers to choose from. With the development of power technology, the optimal design of SMPS is in endless progress. There are many ways to realize the optimal design of SMPS, which can be approximately grouped into the following aspects: (i) using new devices (e.g., the new single-chip SMPS IC); (ii) using new technologies (e.g., magnetic amplifier, synchronous rectification, active clamp, active power factor correction, and digital power supply); and (iii) using new software (the latest version of the computer-aided design software).

In recent years, with the development and application of green energy-saving power supply, the first author of this book gave 15 lectures on "optimal design of SMPS" and "optimal design of LED drive power supply" in the senior seminar held in Beijing, Shanghai, Suzhou, Ningbo, Hangzhou, and Shenzhen at the invitation of several units such as the China Electronics Standardization Institute under the Ministry of Industry and Information Technology and the China Electronics Enterprises Association. Using these lectures as a basis, the authors put many years of their teaching and scientific research experience into this book for both new and old readers.

The book is scientific, advanced, systematic, and practical and has the following features.

First, it describes the optimal design of SMPS in a comprehensive, in-depth, and systematic manner, including new technologies and applications of SMPS, topology selection of DC/DC converter, peripheral component selection of SMPS, optimal design examples of SMPS, key design points of SMPS, and test technology and protection circuit design.

Second, in view that the SMPS current is moving toward single-chip integration, intellectualization, modularization, and the physical features of short, small, light, and thin, it focuses on the optimal design of single-chip SMPS with the most representative single-chip SMPS IC in the world as an example.

Third, it is novel in content. It introduces many new technologies and their application examples such as the half-bridge LLC resonant converter, synchronous rectification, magnetic amplifier regulation, StackFET^{TM} (stacked FET), suspended high-voltage constant current source, valley fill circuit, active power factor correction, and electromagnetic compatibility design of SMPS.

Fourth, it is easy to understand, delivering high practical value. It not only gives various design examples of SMPS but also describes in detail the key design points of circuits, testing methods, selection of key peripheral components, and the design of protection circuit. It has important reference value for readers to research and develop SMPS.

Fifth, it is informative with wide range of knowledge, easy for readers to comprehend and learn by analogy and apply flexibly.

Professor Zhanyou Sha contributed Chapters 1, 2, and 6–8, and completed the review and integration of the whole book. Associate Professor Hongtao Ma, Professor Xiaojun Wang, and Professor Yanpeng Wang jointly contributed Chapters 3–5, 9, and 10.

We would like to express our sincere thanks to Power Integrations (PI), ON Semiconductor, STMicroelectronics (ST), Texas Instruments (TI), Fairchild, and Philips for their help and support.

We would be very glad if the book can be of use for your SMPS design.

Introduction

This book describes the optimal design of switching-mode power supply (SMPS) in a comprehensive, in-depth, and systematical manner. The book includes 10 chapters. Chapter 1 is the overview on SMPS. Chapter 2 describes the new technologies and applications of SMPS. Chapters 3 and 4 introduce the topology of DC/DC converter and the method of selecting key peripheral components of SMPS, respectively. Chapters 5–8 focus on the power factor correction circuit design of SMPS, the design of high-frequency transformer, the examples of SMPS optimization design, and the key design points of SMPS, respectively. Chapters 9 and 10 introduce the SMPS testing technology and the protection circuit design of SMPS, respectively. This book has important reference value for readers to research and develop new-type SMPS.

This book is rich in content and easy to understand with numerous illustration, delivering high practical value. It is suitable for various technicians in the electronic field, university teachers and students, and fans with a passion for electronics.

1

Overview on Switching-Mode Power Supply (SMPS)

1.1 Classification of Integrated Regulated Power Supply

There are tens of thousands of integrated voltage regulators in the market, which can be roughly classified into linear regulators and switching regulators. See Table 1.1 for the classification and characteristics of integrated regulated power supply.

1.1.1 Optimal Design of SMPS

The linear regulator, also known as series regulated integrated regulator, is named for its internal regulating tube, which works in the linear working area and is in series connection with load. It has advantages such as sound voltage regulation performance, low-output ripple voltage, simple circuit, and low cost, while its main disadvantages include relatively bigger voltage drop and high power consumption of the regulating tube with relatively low efficiency of the regulated power supply at about 45%. The linear regulator mainly consists of two types, namely, standard linear regulator using NPN regulating tube, which is also known as NPN linear regulator, and PNP low-dropout (LDO) regulator using PNP regulating tube. Besides, there are quasi low-dropout (QLDO) regulator and very low-dropout (VLDO) regulator. According to the characteristics of output voltage, linear regulators can be divided into different types such as fixed output, adjustable output, positive pressure output, negative pressure output, and multiplexed-output (including tracking output). The efficiency of traditional standard linear regulators is only around 45%, while that of LDO and VLDO can reach 80−90% under low voltage output.

The switching-mode power supply (SMPS) is known as a highly energy-efficient power supply. It leads the development direction of regulated power supply and now has become the leading product of regulated power supply. With the internal key components working under high-frequency switch status, the SMPS consumes quite low energy so that its power efficiency may reach up to 70−90%, twice as high as that of the standard linear regulated power supply. The SMPS integrated circuit mainly consists of the following four types: pulse width modulator (PWM), pulse frequency modulator (PFM), switching regulator, and single-chip SMPS.

According to the circuit principle, regulators can be divided into three types including series regulated linear regulator, shunt regulated linear regulator, and switching regulator.

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Table 1.1 Classification and Characteristics of Integrated Regulated Power Supply

Integrated regulated power supply	Linear power supply	Standard linear regulator	Fixed type	Three-terminal fixed type	Positive voltage output, negative voltage output
				Multiple-terminal fixed type	Positive voltage output, negative voltage output
			Adjustable type	Three-terminal adjustable type	Positive voltage output, negative voltage output, tracking mode
				Multiple-terminal adjustable type	Positive voltage output, negative voltage output, tracking mode
		Low dropout linear regulator	Low dropout regulator (LDO)	Three-terminal or multiple-terminal fixed/adjustable type	Positive voltage output, negative voltage output, tracking mode
			Quasi low dropout regulator (QLDO)		
			Very low dropout regulator (VLDO)		
	Switching mode power supply (SMPS)	Pulse width modulator (PWM)	With relatively low integration level and complicated peripheral circuit with constitutes high-power SMPS		
		Pulse frequency modulator (PFM)	With relatively low integration level, complicated peripheral circuit, switching frequency may reach over 1 MHz, and high efficiency		
		Switching regulator	With relatively high integration level and power switch tube inside, which needs to be equipped with industrial frequency transformer		
		Single-chip SMPS	With pretty high integration level and simple peripheral circuit, which constitutes SMPS of medium and small power		

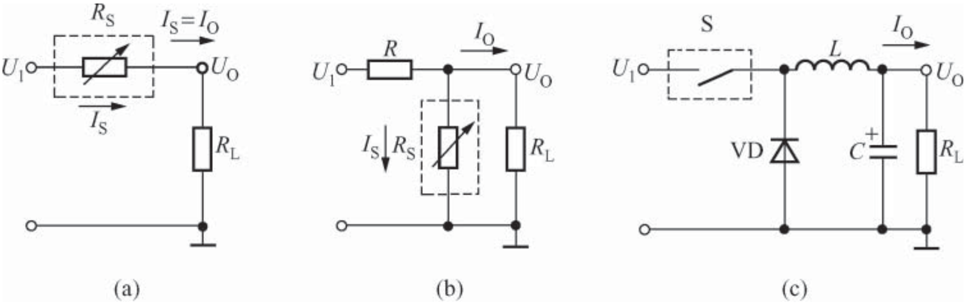

Figure 1.1 Equivalent circuits of the three kinds of regulators: (a) series regulated linear regulator; (b) shunt regulated linear regulator; and (c) switching regulator

Their equivalent circuits are respectively shown in Figure 1.1(a)–(c). In this figure, R_S refers to the equivalent resistance of regulating tube and S the power switch tube. As its output voltage is highly stable and output current is very small, shunt regulated linear regulator is generally used as reference voltage source. The main characteristics of various products are described in the following sections.

1.1.1.1 Three-Terminal Fixed Regulator

Fairchild Semiconductor Corporation firstly launched μ7800 and μA7900 series three-terminal fixed regulators in the beginning of the 1970s. It is a big revolution for integrated circuits of power supply, which greatly simplifies the design and application of power supply. The three-terminal fixed regulator can be placed in the circuits via the simplest way (such as a transistor) and has relatively complete overcurrent protection (OCP), overvoltage protection (OVP), and overheat protection (OTP) functions. At present, μA7800 and μA7900 series three-terminal fixed regulators have become universal ones in the world, with the widest application and largest sale volume. Such a three-terminal fixed regulator is easy to operate and needs no adjustment. It has a simple peripheral circuit and operates reliably and safely, and therefore is applicable to make general or nominal-output regulated power supply. However, it cannot regulate the output voltage or directly output non-nominal voltage, and its voltage is not stable enough.

1.1.1.2 Three-Terminal Adjustable Regulator

Three-terminal adjustable regulator was developed in the late 1970s and the early 1980s, which was the second-generation three-terminal regulator initiated by National Semiconductor (NSC). It not only reserves the advantage of simple structure the three-terminal fixed regulator has but also overcomes the disadvantage that the voltage could not be regulated. Moreover, its voltage stability is increased by one order of magnitude. Therefore, three-terminal adjustable regulator can be used to make laboratory power supply and DC regulated power supply. In addition, it can also be designed as fixed type to replace the three-terminal fixed regulator, to further improve the voltage regulation performance.

1.1.1.3 Low-Dropout (LDO) Regulator

LDO is a high-efficiency linear integrated regulator, whose input–output dropout voltage is about 500 mV, with power efficiency obviously higher than that of NPN linear regulator. VLDO is a new linear integrated regulator developed based on LDO in the beginning of the twenty-first century. VLDO uses the field-effect tube with very low specific on-resistance instead of the power tube that PNP uses, and its input–output dropout voltage can be as low as 45–150 mV.

1.1.1.4 Multiterminal Integrated Regulator

With plenty of pins, the multiterminal integrated regulator is flexible to use but with complicated connections. It can also be classified into fixed type and adjustable type.

1.1.1.5 Tracking Positive–Negative Balanced Output Integrated Regulator

Its characteristic is that when the positive voltage changes for some reasons, the negative voltage output may track automatically and make corresponding change to keep the absolute values of the two equal. The tracking function is particularly important for a precision operational amplifier powered by two supplies, which can prevent the operational amplifier from zero drift rising out of the unbalance between positive voltage and negative voltage.

1.1.1.6 Transformer SMPS without Power Frequency

The SMPS is also known as a low-loss power supply. As its internal parts operate under high-frequency switch status, the SMPS consumes low energy but with power efficiency twice that of ordinary linear regulated power supply.

1.1.1.7 Switching Regulator

A switching regulator is a switch integrated voltage regulator developed in the 1980s and 1990s. With PWM, power output, and protection circuit integrated on the same chip, the switching regulator has efficiency of over 90%. In addition, some switching regulators can even regulate output voltage continuously that can be used to SMPS with dozens to hundreds of wattage.

1.1.1.8 Single-Chip SMPS

With the main circuits (including MOSFET, required analog and digital circuits) of SMPS integrated on chip, the single-chip SMPS with the highest integration level can realize output isolation, PWM, and many other protection functions. A single-chip SMPS fits AC current of 85–265 V and 47–400 Hz via an input rectifier filter; it is thus an AC/DC power converter. The single-chip SMPS integrated circuit has displayed strong vitality since its appearance in the mid-1990s. It has such advantages as high integration level, high cost performance, simplest peripheral circuit, and best performance indicators. Now, single-chip SMPS integrated circuit has become an optimal integrated circuit for the development of medium- and small-power SMPS with wattage below 1000 W, precision SMPS, and SMPS modules. Besides, the development of single-chip SMPS has also created favorable conditions for the optimal design of SMPS.

1.1.1.9 Special SMPS

A special SMPS is characterized by “novelty, uniqueness, and wide application.” It is novel in circuit, unique in function, and advanced in performance, with a great variety and wide application. Its varieties include constant voltage/current SMPS, LED driving power for lighting, constant power SMPS, high-voltage pulse power supply, high-power high voltage power supply, battery charger, and so on.

1.2 Characteristics of SMPS

1.2.1 Main Characteristics of SMPS

The SMPS is also called low-loss power supply. With its internal components working in a high-frequency switch status, it consumes low energy, and its power supply efficiency is twice that of the ordinary linear regulated power supply. The integrated circuits for SMPS are classified into two types: one is singled-ended or double-ended output PWM and the other is PFM, both of which can constitute the SMPS without power frequency transformer. Because they realize the voltage transformation and grid isolation with high-frequency transformer of very small volume, they can save power-frequency transformer of cumbersome volume. At present, the work frequency of SMPS has been increased from 20 kHz to hundreds of kilohertz and even above 1 MHz, so has the power efficiency. The output power range includes low power (dozens of wattage), medium power (hundreds of wattage), and high power (thousands of wattage). The disadvantage of SMPS is that the output voltage is not stable enough, and the output ripple is large and its noise is loud, making it inappropriate for making precise regulated power supply. However, it can be used as a pre-voltage regulator, with the standard linear regulator or low dropout linear regulator as the post-voltage regulator to constitute a high efficiency and precise regulated power supply of two stages. Such compound power supply possesses the advantages of SMPS and linear power supply.

Compared with the linear power regulator, although the SMPS is of complex design and some performance indicators are inferior to those of the linear regulator and the noise is loud, the advantages of SMPS mainly lie in the power efficiency, volume, weight, and so on. Especially when it constitutes a high-power regulated power supply, its volume is greatly reduced compared with that of the linear regulated power supply under the condition of the same output power, and the costs also decline significantly.

The efficiency of SMPS generally ranges from 70% to 85% with the maximum of 90%. Equipped with the post-positioned linear regulator and constituting a compound regulated

Table 1.2 Performance comparison of 20 kHz SMPS and linear regulated power supply

Parameter	SMPS	Linear regulated power supply
Power efficiency (%)	70–85	30–40
Output power per unit volume (W/cm^3)	0.12	0.03
Output power per unit mass (W/kg)	88	22
Voltage regulation rate (%)	0.1–1	0.02–0.1
Load regulation rate (%)	1–5	0.5–2
Output ripple voltage (mV, peak–peak value)	50	5
Output noise voltage (mV, peak–peak value)	50–200	Extremely small
Transient response time (μs)	1000	20
Holding time of output voltage after power failure (ms)	20–30	1–2

power supply, it still can achieve a high efficiency ranging from 60% to 65%, while the efficiency of most of the linear regulated power supplies (excluding low dropout linear regulators) only ranges from 30% to 40%. Compared with the linear regulator, the overall size of the traditional 20 kHz SMPS is only 1/4 of that of the linear regulator, and the 100–200 kHz SMPS is 1/8, while the size of new 200 kHz–1 MHz SMPS can be much smaller. After the power outrage, the SMPS can maintain the output voltage for a longer time than the linear regulator, because the latter is generally equipped with a low-voltage input filter capacitor, while the former is equipped with a high-voltage input filter capacitor with the withstand voltage ranging from 200 to 400 V and it saves more charge Q because of the direct proportion between Q and $CU_1{}^2$ (U_1 is DC high voltage).

The disadvantage of the SMPS is that it has relatively low-voltage regulation rate and load regulation rate, which takes a long time to respond to the transient state of load change; the output ripple and noise voltage are relatively high so that it is likely to exert electromagnetic interference externally.

1.2.2 Performance Comparison of SMPS and Linear Regulated Power Supply

See Table 1.2 for the performance comparison of 20 kHz SMPS and linear regulated power supply. It can be seen from the table that many technical indicators of the SMPS are superior to those of the linear regulated power supply.

1.3 New Development Trend of SMPS

The SMPS has been developed for decades. The self-excitation push-pull type transistor single transformer DC converter invented in 1955 took the lead in realizing the high-frequency conversion control function; and the one invented in 1957 and the SMPS design without power frequency transformer plan proposed in 1964 forcefully promoted the technological progress of the SMPS. The emerging of the PWM in 1977 and the single-chip SMPS in 1994 paved the way for promotion and popularization of the SMPS. Meanwhile, the frequency of SMPS has also increased from 20 kHz at the beginning to hundreds of thousands of hertz, and even a couple of megahertz. The SMPS is developed to be highly efficient, energy-saving, safe, environment-friendly, short, small, light, and thin. A variety of new technologies, processes, and apparatuses spring up like mushrooms and emerge continuously and the application of SMPS has also been increasingly popular. Next, introduction will be made on the new trend and new technology for the development of SMPS.

1.3.1 New Development Trend of SMPS

1.3.1.1 Green and Energy-Saving SMPS

Many famous integrated circuit manufacturers are making great efforts to develop low-power consumption and energy-saving SMPS integrated circuit. For example, Power Integrations (PI) of the United States adopted the energy-saving technology EcoSmart® to develop single-chip SMPS such as TOPSwitch-HX series. PI announced recently that due to the single-chip SMPS IC EcoSmart®, as it would save electric charge of about USD 3.4 billion for consumers all over the globe. The Green Chip such as TEA1520 series launched by Philips of the Netherlands also attaches great importance to high efficiency and energy saving functions. Besides, the international standards for green and energy-saving power supply have also been widely applied. For instance, the United States has established Energy Star Program in 1992 to reduce the no-load power consumption of the SMPS. The compulsory energy-saving standards established by California Energy Commission (CEC) have been implemented from July 1, 2006, requiring that the standby power consumption and no-load power consumption of electronic products must be reduced substantially. These standards cover all electronic products using external power adapter or charger, including mobile phone, household appliance, portable music player (MP3), handheld game player, electronic toys, and so on.

According to the fourth edition of power saving standard (Code of Conduct) newly published by the European Commission, which came into effect since January 1, 2009, specified that the no-load power consumption of ordinary power supply with rated output power of 0.3–50 W shall not be more than 0.30 W and that of ordinary power supply with rated power of 50–250 W shall not be more than 0.50 W. The new standard raised stricter requirements on the no-load power consumption of mobile phone power supply of 0.3–8.0 W, requiring it not to exceed 0.25 W during January 1, 2009 and December 31, 2010 and 0.15 W from January 1, 2011.

1.3.1.2 Intelligent Digital Power Supply and Programmable SMPS

Digital Power Supply

At present, the SMPS is developed to be intelligent and digitalized. The intelligent digital power system, which emerged at the beginning of the twenty-first century, has drawn great attention of the public for its excellent performance and advanced monitoring functions. The digital power supply, being intelligently adaptive and flexible, is able to directly monitor, process, and adapt to the system condition and meet any complex power requirement. In addition, it also guarantees the reliability of the long-term system operation through remote diagnosis, including fault management, overcurrent protection, and preventing the system from stop.

The promotion of digital power supply created a favorable condition for the optimal design of intelligent power system.

The digital power system has the following features:

1. It is an intelligent SMPS system with a digital signal processor (DSP) or micro controller unit (MCU) as the core and the digital power driver and PWM controller as the control object. The traditional SMPS controlled by MCU (including MCU μP and single-chip machine μC) generally controls only the switch-on and switch-off of the power supply, which is not a digital power supply in real sense.
2. Developed with fusion digital power technology, it realizes the optimal combination of analog element and digital element in the SMPS. For example, the analog element used for the power stage – MOSFET driver can be conveniently connected to the digital power controller and help to manage the power protection and biasing circuit. PWM controller also falls into the category of digital control analog chip.
3. With high integration, it realizes power system on chip, integrating a big number of separated components into a chip or a set of chips.
4. It can make full use of the advantages of DSP and MCU, making the digital power designed reach high technical indicators. For example, the resolution of its PWM can reach 150 ps (or 10^{-12} s), far exceeding the traditional SMPS. The digital power supply can also realize many functions such as multiple phase control, nonlinear control, load share, and fault prediction providing convenience for the research and manufacturing of green and energy-saving SMPS.
5. It provides convenience for building a distributed digital power system.

In March 2005, Texas Instruments (TI) of the United States announced to launch innovative digital power products and displayed the solution of Fusion Digital Power™ that includes the following three types of chips: UCD7K series digital power drivers, UCD8K series PWM controllers, and UCD9K series digital signal processors. Product series have been formed for the above- mentioned chips, supporting both the AC circuit and load power systems. They can be widely applied in telecommunication facilities, computer server, data center power system, and UPS.

Programmable SMPS

The adjustable SMPS changes the output voltage of regulator by manually regulating the resistance value, which is not only precise enough, but also inconvenient for application. Digital potentiometer, which is also called digitally controlled potentiometer (DCP), can replace the adjustable resistance to constitute a programmable SMPS under computer-based control.

The circuit design plan for the programmable SMPS constituted by digital potentiometer is shown in Figure 1.2. Figure 1.2(a) shows replacement of adjustable resistance with DCP, which works in the adjustable resistance model. The adjusted resistance value is R_{DCP}, which, together with R_1, constitutes a sampling circuit$_1$, which is sent to the feedback terminal FB of the switching regulator. The single-chip microcontroller can set the output voltage of adjustable switching regulator by changing the value of R_{DCP}. The second plan is to replace two sampling resistors with R_{DCP} simultaneously, which can save one resistance element, whose simplified circuit is shown in Figure 1.2(b) with other parts being the same with Figure 1.2(a). The third plan is to connect the DCP between R_1 and R_2 in series; the simplified circuit is

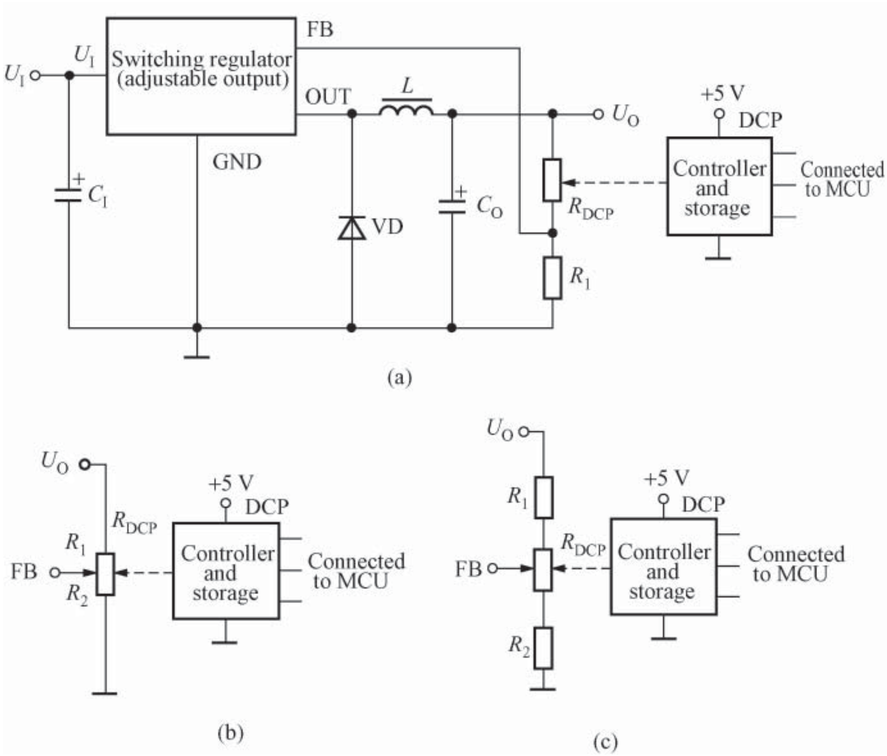

Figure 1.2 Circuit design plan for programmable SMPS constituted by DCP (a) Circuit 1; (b) Circuit 2 (simplified circuit); and (c) Circuit 3 (simplified circuit)

shown in Figure 1.2(c). This circuit is applicable to the fine regulation of output voltage in a small range.

1.3.2 New Technology in the SMPS Field

1.3.2.1 Active Clamp Technology

The function of clamp circuit is to clamp down the peak voltage generated by the SMPS at work time within a certain range in order to protect the power switch tube. The clamp circuits can be divided into passive clamp circuits and active clamp ones. The general R, C, and VDz clamp circuits belong to passive clamp circuits. The advantage of such passive clamp is that it has a simple circuit and can absorb the peak voltage generated by leakage inductance of high-frequency transformers. However, the clamp circuit has larger energy consumption itself, thus reducing the power supply efficiency.

The active clamp circuit invented by VICOR of the United States can significantly reduce power loss of the SMPS. The typical active clamp circuit is shown in Figure 1.3. The active clamp circuit was named for an active power component, MOSFET (V_4), which is used as clamper tube in the circuit. In Figure 1.3, C_c is the clamp capacitor and V_3 is the power switch

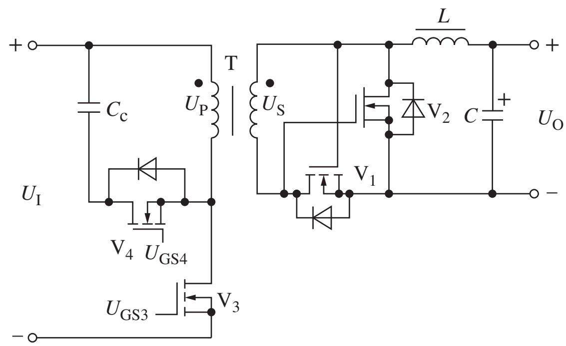

Figure 1.3 Active clamp circuit

tube of SMPS. It can be seen from this figure that U_{GS3} is 0 when V_4 is on, switching V_3 off and U_{GS3} will switch V_3 on when V_4 is off, thus clamping the peak voltage generated by leakage inductance of high-frequency transformers.

1.3.2.2 Synchronous Rectification (SR) Technology

Synchronous rectification (SR) was developed at the end of the twentieth century. It is a new technology of using the special power MOSFET with extremely low on-state resistance instead of rectifier diode to reduce the rectifier loss, which can significantly improve the efficiency of SMPS under low voltage and large current output. SR circuit adopts power MOSFET or Schottky Barrier Diode (SBD) as rectifier tube, requiring that the grid voltage should keep synchronous with the phase of rectified voltage to complete the rectification function. Therefore, it is called SR. For the synchronous rectifier comprising field effect transistor or SBD launched by Onsemi recently, the forward on-state voltage drop generally ranges from 0.2 to 0.4 V and the reverse recovery time is only 100 ns.

1.3.2.3 Soft Switching Technology

The general PWM-type SMPS adopts a “hard switching” technology, with which the voltage or current on VT is not zero when the power switch tube VT is either on or off. Nevertheless, the VT is forced to be on or off when the voltage or current is not zero, thereby increasing the switching loss. The switching loss includes the capacitor loss and the switch overlapping loss of the power switch tube. The capacitor loss, which is also called CU^2f loss, refers to a loss caused by discharging of the distributed capacitance of power switch tube when each switching cycle starts. The switch overlapping loss, caused by the switching time of the power switch tube, increases with the rising of switching frequency, which not only limits the development of high-frequency SMPS, but also easily generates electromagnetic interference.

Soft switching technology shall be introduced to make up the defects of “hard switching” technology. Soft switching refers to zero voltage switching (ZVS) or zero current switching (ZCS). With ZVS and ZCS, the power switch tube can be switched off when voltage and current crossing zero respectively, so as to minimize the switching loss for the purpose of improving the power supply efficiency and protecting the power switch tube.

1.3.2.4 Magnetic Amplifier Regulator Technology

A magnetic amplifier is composed of sampling circuit, reference voltage source, magnetic reset control circuit, controllable magnetic saturation inductor, and PWM. The controllable magnetic saturation inductor acts as a controllable magnetic switch in the voltage regulator circuit, which can accurately regulate the pulse width only by changing the delay time of magnetic reset to achieve accurate voltage regulation. Therefore, the magnetic amplifier is equivalent to an external PWM.

In the positive and negative voltage symmetrical output SMPS, using magnetic amplifier voltage regulator circuit can not only improve the precision of voltage regulation, but also increase the rate of cross loading regulation.

1.3.2.5 New Technologies for Single-Chip SMPS Application

With the increasing popularization of the single-chip SMPS, new technologies are also applied in the circuit design. The following examples are given for illustration.

1. StackFET^{TM} (stack field effect transistor) technology. The single-chip SMPS is integrated with a power field effect transistor MOSFET with a drain-source electrode breakdown voltage of 700 V. When the maximum AC input voltage $U_{I\ (max)}$ is 580 V, the maximum primary voltage of high-frequency transformer reaches nearly 1050 V (including primary induced voltage U_{OR}, which is also called secondary reflected voltage), far above 700 V. To avoid any damage to the internal MOSFET, an MOSFET power field effect tube V can be stacked on its drain electrode as external MOSFET. These are the features of the StackFET circuit.
2. Design of industrial control power supply with ultrawide input range. To ensure that TinySwitch-III can work normally under ultralow AC input voltage, a floating high-voltage constant-current source shall be added exteriorly for the purpose of continuously supplying power to bypass end under low voltage. This technology is applicable for designing industrial control power supply with an ultrawide input range of 18–265 V.
3. PFC circuit. To improve the power factor of SMPS and reduce the total harmonic distortion (THD), AC/DC converter shall be provided with a power factor correction (PFC) circuit. Passive “valley fill circuit” (VFC) can be adopted when high-output ripple voltage (such as the driver composing white light LED lamp) is not required. VFC is used to greatly increase the conduction angle of rectifier diode, changing the input current from peak pulse into a wave form approaching sine wave via filling the valley points. The universal high-power SMPS is generally equipped with a new special chip with active PFC to simplify the circuit design.
4. Single-chip high-power SMPS. In recent years, the maximum output power of single-chip half-bridge LLC resonant converter with PFC, single-chip double-switch forward converter and other chips newly developed by chip manufacturers has reached 600–1000 W, creating favorable conditions for development of cheap high-power SMPS of high quality.
5. LED lighting driving power supply. LED lighting, also called semi-conductor lighting or solid state lighting, falls into the category of energy-saving and environment-friendly

"green lighting" characterized by low power consumption, high luminance, vibration resistance, long service life, small overall dimension, quick response, no pollution to environment, and other noticeable advantages. LED driving power supply is a power unit exclusive for power supply to LED lamps. At present, using new technologies and new processes, chip manufacturers have successively developed a batch of application-specific integrated circuit (ASIC) with advanced performance and unique characteristics. These chips have not only retained the advantages of SMPS chips, such as high efficiency and energy saving, but also are featured by constant current output, dimmable function, and PFC.

1.3.2.6 Highly Reliable Modular Design

It is well-known that integration technology cannot integrate the high-capacity capacitor, inductor, rectifier bridge, potentiometer, and high-power components of 10 A and above into a chip. Therefore, to develop an SMPS, a chip should be selected, the peripheral circuit should be designed, and the printed circuit should be designed as well, which brings inconvenience to users. However, the problems mentioned earlier can be readily solved if a power supply block is used.

The power supply block is a commodity component assembling power supply integrated circuit and miniature electronic components (such as pellet resistance and subminiature electrolytic capacitor) by microelectronic technique to complete a certain specific function. With the structural feature that all components are densely installed on a printed board, so the power supply block is also called secondary integration. The power supply blocks are generally divided into two categories by appearance: totally enclosed and non-removable ones and open ones.

Compared with the traditional whole machine, the whole machine composed of power supply block has the following prominent features: the circuit design can be greatly simplified so that the development cycle of new products can be shortened; with advanced technology and process, the qualified rate and reliability of the whole machine can be improved, and the one-time qualified rate is up to 100%; the volume and weight can be reduced; the machine is easy to install and maintain; and the use of totally enclosed power supply block can prevent forging, so as to protect the rights and interests of manufacturers.

At present, the power supply block is also developed to be intelligent. For example, the intelligent power supply block has achieved higher technical indexes (600 A, 600 V, with various protection functions and the failure self-detection and display function). The mean time between failures (MTBF) of single block has reached 10^7 h with the volume of the block gradually reduced. With the development of surface mount device (SMD) and surface mount technology (SMT), the volume of the power supply block will be further reduced while the performance indicators will be significantly improved.

1.3.2.7 Realization of SMPS Optimal Design Using Software

In recent years, with the development of power supply technology and the popularization of computer application, it has become a new technology in the international power supply field to design the SMPS using computer. At present, software has become the key technology for