Development of Buck Converters

As the power center of electronic products, the battery life of the power supply directly determines the service life of electronic products. With the continuous progress of IC (Integrated Circuit) process technology, the power supply voltage of digital circuits has been declining, but the power supply of the system is still at a higher voltage. Therefore, it must rely on buck converters to provide a lower power supply voltage. Before the advent of switching power supply technology, linear power supplies were the main power supply of various electronic products. They can realize the conversion from high DC voltage to low DC voltage, suitable for low-dropout voltage conversion and low-load current applications. To improve the performance of electronic products and save energy, it is crucial to solve the power performance issues. Because of its low power consumption, high-conversion efficiency, and low cost, switching power has gradually replaced linear power and has been widely used in the electronics industry.

At the beginning of the development of switching power supplies, discrete devices and simple asynchronous rectification technology were commonly used at the power stage, as shown in Figure 1.

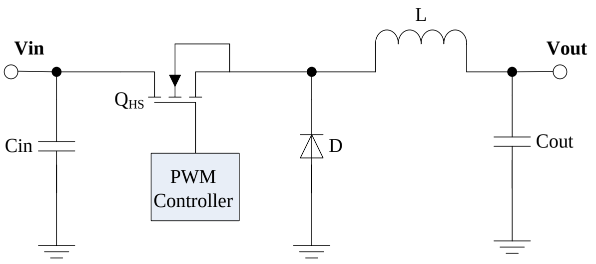

Figure 1. Asynchronous Rectification DCDC Buck Converter

The synchronous rectifier technology uses MOSFETs instead of rectifier diodes. Due to the low on-resistance of MOSFETs, the on-loss of the rectifier device is greatly reduced, improving the conversion efficiency. The synchronous rectifier technology is particularly suitable for low-voltage and high-current applications. The synchronous rectification buck converter is shown in Figure 2.

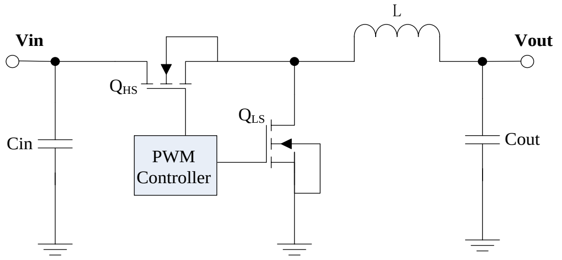

Figure 2. Synchronous Rectification DCDC Buck Converter

In the mid and late 1990s, with the development of ICs, discrete MOSFET components were integrated into chips, and the overall performance of DCDC buck converters was greatly improved. However, the cost was reduced, showing strong vitality. For the buck converter with a not very large current, PMOSFET is commonly used for the high-side switch at the power stage, making the control circuit simple. For high-current buck converters, economical NMOSFET is used instead. The gate voltage of the NMOSFET needs to be raised through the bootstrap circuit, as shown in Figure 3.

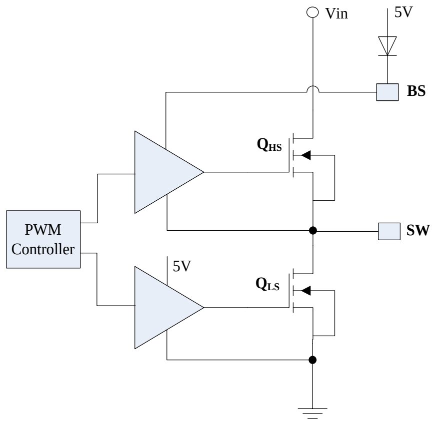

Figure 3. Synchronous Rectification DCDC Buck Converter with Bootstrap Circuit

The control scheme for the DCDC buck converter has voltage mode control (Figure 4) and current mode control (Figure 5) according to the control loop.

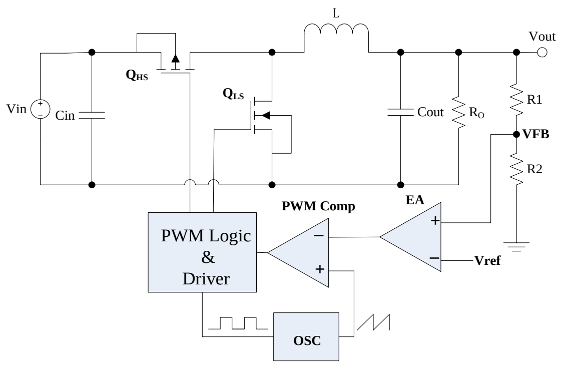

Figure 4. Voltage Mode Control DCDC Buck Converters

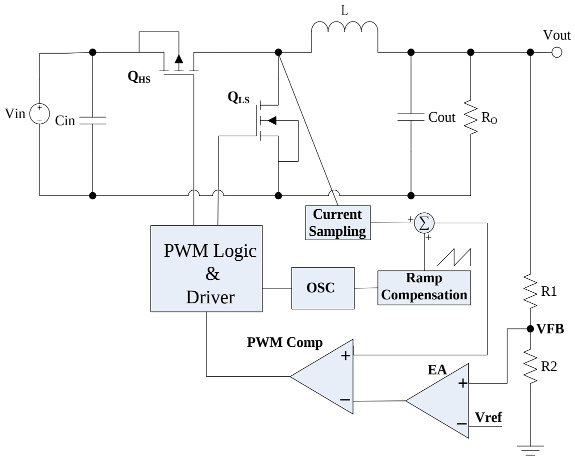

Figure 5. Current Mode Control DCDC Buck Converters

The voltage control mode of the DCDC buck converter is characterized by a simple structure. It features slow dynamic response, double poles, and complex compensation due to only one voltage feedback loop. Based on the voltage control mode, a current feedback loop is added to the current control mode, which results in a dual-loop control system with a voltage feedback outer loop and current feedback inner loop. The current-mode control has a fast closed-loop response and easy compensation for a single-pole point system. However, when the duty cycle (D) is greater than 50%, it is prone to sub-harmonic oscillation. Various harmonic compensation circuits have emerged to make up for this shortage. For a long time, current mode control DCDC has been the mainstream of power supply.

Moore's Law has led to shrinking linewidths in the semiconductor process, and portable devices such as smartphones, tablets, and digital cameras have become ever thinner and more powerful. However, the voltage of the power supply required by digital products continues to decline while the current continues to increase, and the demand for the performance of the power supply is constantly increasing. The traditional PWM mode DCDC can no longer meet the needs of the market.

COT (Constant-On-Time) control architecture has been widely used in recent years. DCDC with COT architecture has several advantages:

1. Simple control circuit, no error amplifier, and current sampling resistance.

2. Fast load regulation.

3. Higher efficiency even under light loads.

The voltage across the ESR (Equivalent Series Resistance) of the output capacitor comes with inductive current information. As long as its "information" is sufficient (meaning the generated ripple can be compared with the capacitor ripple), it can be used as a current sensing resistor to achieve the current mode control [1] [2] [3] using only the output voltage. In applications where the output voltage ripple can be high, a resistor can be in series with the capacitor to produce such a ripple signal, as shown by R3 in Figure 6.

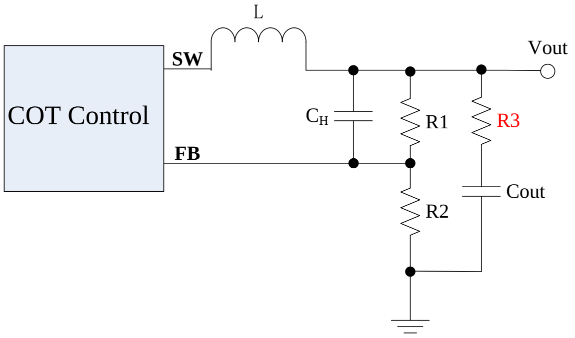

Figure 6. COT Application Circuit

Capacitors with high ESR (electrolytic capacitors, solid state capacitors (OSCON), polymer organic semiconductor solid capacitors (POSCAP)) are usually used to achieve this ripple. Driven by strict output adjustment voltage specifications and the need for cost and size compression, power supply designers turn to using ceramic capacitors with lower cost, smaller size, and lower ESR [1]. When using the COT architecture with ceramic capacitors, it is necessary to "build" a ripple with inductance current information of sufficient amplitude, as shown in Figure 7. The generated ripple can be calculated by Equation 1.

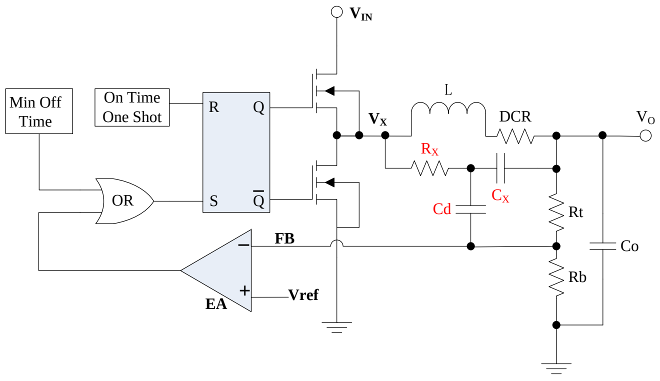

Figure 7. Ripple Generating Circuit for COT DCDC Buck Converter

$$V_{CX(PP)} = \frac{I_{L(PP)} \times L}{R_X \times C_X}$$

Equation 1.

Another application of the same chip is shown in Figure 8. To achieve a lower output voltage ripple, R3 is removed. Instead, RA and CA are used to produce a ripple with enough inductance current.

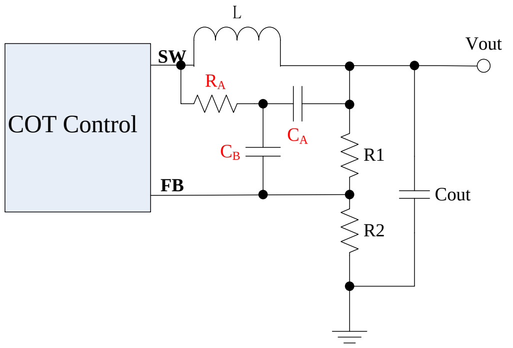

Figure 8. Minimum Output Ripple Using Ripple Injection

The TPP2020 DCDC buck converter developed by 3PEAK adopts COT technology, with an input voltage of up to 20 V, an output voltage ranging from 1 V to 5 V, and an output current of up to 3 A. Its efficiency can reach up to 93%. The typical application of the TPP2020 is shown in Figure 9.

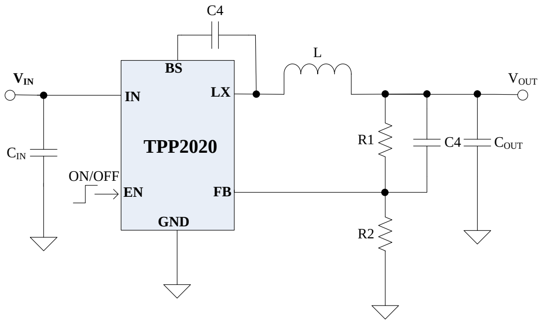

Fig. 9. TPP2020 Application Circuit

With the development of microelectronics technology and the need for power supply for electronic products, the DCDC buck converter has been continuously innovated. It has evolved from asynchronous rectifier to synchronous rectifier, from discrete off-chip MOSFETs to integrated high-power MOSFETs on the chip, from single-loop voltage mode to dual-loop current mode, from the complex loops and compensation circuit to simple COT architecture (without error amplifier, compensation circuit, even the oscillator), and from PWM to PFM mode. Nowadays, COT architecture has been vigorously developed in the field of power supply with its incomparable advantages. In the future, new technologies will continue to be created and integrated, making the performance of our DCDC buck converters more outstanding.

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