Design of a new type of F-COFT controlled BUCK-BOOST converter

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Abstract. As an important method of pulse frequency modulation (PFM), constant off-time (COFT) is widely used in switching power. However, the switching frequency changes with the input and output voltage, which increases the power consumption of the switching power and is prone to high electromagnetic interference (EMI). Therefore, a new fixed frequency COFT control method (F-COFT) is designed. By designing a charging timing circuit that carries input and output voltage information, the input and output voltage information is fed back to the timing module to realize dynamic adjustment of the constant-off time to ensure the stability of the frequency and eliminate the influence of frequency changes on the circuit. Through LTSPICE simulation, the feasibility of the scheme is verified.

1. Introduction
Nowadays, people are inseparable from electronic products. With the continuous emergence of new technologies, the performance of electronic products has been improved and gradually realized intelligence, which has made people's lives easier. However, electronic products are inseparable from DC power supplies. Commonly used DC power supplies include DC linear regulated power supplies and DC switching power supplies. Switching power supply is a kind of power supply that uses modern power electronic technology to control the time ratio of switching transistors on and off to maintain a stable output voltage and current [2]. Buck-Boost converter is one of the DC switching power supplies. Due to its topological characteristics, it can output a certain range of negative voltage, so it is often used as a power supply in dual power supply systems, such as A/D conversion circuits, D/A Conversion circuit, operational amplifier circuit audio circuits, etc., are especially used in OLED displays that have appeared in recent years. OLED display has the advantages of self-illumination, wide viewing angle, high image quality, low power consumption, ultra-thin, strong flexibility, etc. [5-7], and is gradually replacing the existing display with viewing angle, slow response speed, passive light emission, and high temperature resistance. The liquid crystal display (LCD) with poor disadvantages [8-11] has become a recognized next-generation flat panel display technology. The normal operation of the OLED display requires a negative voltage as one of the driving power sources, which makes the Buck-Boost converter a research hotspot in recent years.
As a control method of PFM, fixed off-time (COFT) has a faster transient response than pulse width modulation (PWM), which solves the shortcomings of low PWM light load efficiency, but due to the constantly changing switching frequency will cause noise and generate large EMI, even causing the switching frequency to reach the audio range. So this article designed a new timing circuit to solve the problem of switching frequency change, and verified its practicability through LTSPICE simulation and Cadence simulation.

2. F-COFT control technology of BUCK-BOOST converter

The traditional fixed off time (COFT) control technology is to charge the charging capacitor through a timing circuit after receiving the pulse signal that the switch tube is turned off, and when it reaches the set voltage, it will output a charged pulse signal and pass the RS After the trigger, let the main switch for the next cycle. This period of time is the fixed off time.

After the circuit parameters of the BUCK-BOOST converter are determined, Toff will not change. When BUCK-BOOST works in the continuous conduction mode of inductor current, the duty cycle D in one cycle is:

\[ D = \frac{V_o}{V_o - V_{in}} \]  \hspace{1cm} (1)

\[ D = \frac{T_{on}}{T_{on} + T_{off}} \]  \hspace{1cm} (2)

So, the fixed off time Toff is:

\[ T_{off} = T \frac{V_{in}}{V_{in} - V_o} = \frac{V_{in}}{(V_{in} - V_o) f} \]  \hspace{1cm} (3)

T is the switching period and f is the switching frequency. It can be seen that when the Toff of the BUCK-BOOST converter is fixed, the switching frequency changes with the input and output voltage. The change of switching frequency will not only increase the power consumption of the switching power supply, but also bring high EMI, which is not conducive to circuit design.

Figure 1 is the schematic diagram and waveform diagram of the BUCK-BOOST converter controlled by COFT.
Because the fixed turn-off time $T_{off}$ of a BUCK-BOOST converter determined by a circuit parameter is constant, it can be known from equation (3) that if the switching frequency $f$ is constant, it is only necessary to let $T_{off}$ follow $V_{in}$ and $(V_{in}-V_{o})$. Dynamic changes can be made. The switching period $T$ is inversely proportional to $V_{in}$ and directly proportional to $(V_{in}-V_{o})$. So only design a charging circuit that makes the charging current of the charging time $T_{off}$ proportional to $(V_{in}-V_{o})$ and the reference voltage of the charging capacitor is proportional to $V_{in}$. It can realize that $T_{off}$ follows the dynamic changes of the input and output voltages, thereby ensuring that the switching period $T$ remains unchanged, that is, the switching frequency $f$ does not change.
As shown in Figure 2, F-COFT has one more voltage feedback loop than traditional COFT. When the main switch is turned off, that is, when COFT\_EN is low, the capacitor C2 starts to charge from 0, and its charging voltage is:

$$U_{c2} = k(Vin - Vo)t$$  \hspace{1cm} (4)

When UC2 rises to the set threshold voltage $V_{CV}$, the threshold voltage $V_{CV}$ expression is:

$$U_{CV} = mVin$$  \hspace{1cm} (5)

The fixed turn-off timer outputs a pulse signal VR to reset the RS flip-flop, that is, COFT\_EN gets a high-level pulse to discharge the capacitor C2 instantaneously, and the voltage of UC2 drops to 0. At this time, the main switch tube is turned on and enters the next switch cycle. Setting (4) and (5) equal, the charging time $t$, which is the Toff, can be calculated as:

$$Toff = t = -\frac{mVin}{k(Vin - Vo)}$$  \hspace{1cm} (6)

So, Toff is a function of input and output voltage, and it changes dynamically with input and output voltage. Let (3) and (6) be equal, we can get:

$$f = \frac{m}{k}$$  \hspace{1cm} (7)

From equation (7), it is easy to conclude that the switching frequency of F-COFT is constant, only determined by the constants $m$ and $k$ determined by the circuit parameters.

Through theoretical analysis, it can be known that once the circuit parameters of the BUCK-BOOST converter are determined, the frequency can be fixed, so as to ensure that the BUCK-BOOST converter controlled by F-COFT works in a constant frequency state.

**Fig 2.** F-COFT controlled BUCK-BOOST converter
3. Simulation of BUCK-BOOST converter controlled by F-COFT

Adopt LTSPICE and Cadence simulation software to carry on the board-level and tube-level circuit simulation respectively, through building the simulation circuit, carry on the F-COFT control BUCK-BOOST converter to carry on the wave form simulation, and carry on the analysis. The circuit simulation parameters are as follows:

| variable | Definition               | value  | unit |
|----------|--------------------------|--------|------|
| Vin      | Input voltage            | 3.7-4.2| V    |
| L        | inductance               | 4.7    | uH   |
| C        | Output capacitor         | 20     | uF   |
| f        | operating frequency      | 1.7    | MHz  |
| UCV      | Threshold reference voltage | 2.5  | V    |
| R        | Load Resistance          | 13.3-40| Ω    |
| Vo       | The output voltage       | -4     | V    |

Set reference voltage VCV=2.5V, output voltage Vo=4V, Vin=3.7V, set f=1.7MHz, and theoretically calculate T=580588ns and Toff=288ns. The actual results are as follows:

![LTSPICE simulation waveform](image)

It can be seen from Figure 3 that the error between the simulation result and the theoretical calculation is very small, the actual T=588ns, Toff=288ns.

Cadence simulation verification was also carried out, and linearity and load jump verification were carried out respectively. The results are as follows:
It can be seen from Figure 4 that when the input voltage jumps from 3.7V to 4.2V at 50us, the circuit reacts very quickly. Although the input voltage increases, the threshold reference voltage changes dynamically, resulting in a constant turn-off time. Change so that the frequency is stable.

It can be seen from Figure 5 that the load jump time and the circuit response speed is very fast. The following two enlarged ripple diagrams can be seen, when the load jumps, the peak-to-peak voltage ripple is from 5mV to 15mV, the voltage change value is 10mV, the error is 0.25%, and the period can be seen that the difference is not much, and the theoretical calculation Match.
4. Conclusion

Based on the traditional fixed off-time (COFT) mode, this paper improves the frequency changes in the traditional COFT, which leads to high power consumption and high EMI, and proposes a new constant-frequency fixed off-time (F-COFT) control method. LTSPICE simulation and Cadence simulation verification were carried out with the actual BUCK-BOOST converter, the theory and principle were analyzed, and the feasibility was verified. Although there will be a small ripple jitter, it still meets the engineering needs of switching.

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