Design of Multiple-output DC/DC Converter Based on Magnetic Amplifier (ECRIM)

Abstract: This paper briefly describes the operating principle of the magnetic amplifier, and then focuses on the application of the magnetic amplifier in multiple output DC/DC converter, finally the test data and related waveforms of the real product are given.

Key Words: magnetic amplifier, multiple-output DC/DC converter

1. Overview

With the acceleration of the process of social industrialization, the development of electronic products is changing with each passing day, the integration of products, miniaturization trend is also inevitable. In military electronic systems, especially in aerospace systems, even the simplest digital single-chip microcomputer system, its power supply voltage is composed of +5V, ±12V and other multi-channel.

In the multi-output power supply, the main circuit output still adopts the traditional feedback structure, and the other auxiliary circuit output can be regulated by the magnetic amplifier, which has the characteristics of simple circuit, low power dissipation and high voltage stabilization accuracy.

2. Comparison of Circuit Design Schemes for Multi-output DC/DC Converter

Different electronic systems have different requirements for the combination of output voltages, and there are strict requirements for the electrical characteristics of the power supply. Taking three-way output power supply as an example, most of the current three-way output power supply design schemes are in the following three types, as shown in Figure 1, Figure 2 and Figure 3:

![Fig. 1 Three output power supply with main and auxiliary circuits](image-url)
Scheme 1 (Fig. 1) is simple in structure and convenient in realization, but the auxiliary circuit has no voltage stabilizing circuit and the primary and secondary turns of the transformer are fixed, so the output voltage of the auxiliary circuit is greatly affected by the load, and there are two items in the electrical performance index of the switching power supply, namely, the cross adjustment rate and the load adjustment rate, which are difficult to meet the ideal requirements of the circuit using this scheme.

Scheme 2 (Figure 2) uses a linear regulator in the auxiliary circuit, which can make up for the defects in scheme 1, but the output current of the linear regulator is usually not large and has certain restrictions, so this scheme is suitable for the power supply with small output current of the auxiliary circuit, and the power loss of the linear regulator is very large, which will reduce the overall efficiency of the power supply.

Scheme 3 (Fig. 3) has strong versatility, because it is composed of two power supply loops, its PWM control circuit and transformer are independent of each other, and the use of
synchronization mode can reduce the mutual interference between different outputs and reduce the output ripple peak.

Each of the above three schemes has its own advantages and disadvantages, in order to meet the requirements of power supply under the condition of product miniaturization, the magnetic amplifier scheme has attracted wide attention.

This scheme is similar to the second scheme, here is the use of magnetic amplifier circuit instead of linear voltage regulator circuit. Because of the magnetic amplifier high efficiency, high voltage regulator accuracy and other characteristics, so that the switching power supply is accurately controlled, while the magnetic amplifier in the final most of the energy back to the circuit, so that auxiliary power loss is reduced, thus improving the overall efficiency of switching power supply.

For a DC/DC converter with only three outputs, as described in Figure 4, for a switching power supply with more outputs, a secondary circuit with a magnetic amplifier can be added again.

![Fig. 4 Typical application circuit with auxiliary magnetic amplifier](image)

Working principle of magnetic amplifier

The magnetic core of magnetic amplifier is usually composed of amorphous alloy with high permeability, low loss at high frequency and rectangular hysteresis loop. According to the different metal materials used in the production process, it can be divided into iron-based amorphous and cobalt-based amorphous.

A magnetic amplifier can be described as a switch tube similar to a high-speed switch when operating. As long as the choke coil is not saturated, the switch is opened and the circuit cannot output; as soon as the core material reaches saturation, the switch is turned on and the circuit begins to output. The magnetic amplifier is constructed by winding a coil on the core using this saturation core characteristic. Figure 5 shows a typical rectangular hysteresis loop.
When the magnetic amplifier starts to work, the positive voltage VI is added, and the magnetic core is magnetized from the direction of 24. Because the hysteresis loop is a rectangular hysteresis loop, the magnetization of the magnetic core is located at a position where the slope of the hysteresis loop is very large, and the impedance of the magnetic core is very large, at this time, the magnetic amplifier is equivalent to a turn-off switch. The magnetic induction intensity + B in the magnetic core at 4 positions is Bs, the magnetic core is saturated, and the impedance is zero. At this, the magnetic amplifier is equivalent to a single-switch operation in a closed state. If a reverse voltage -Vi is applied to the saturated magnetic amplifier, the magnetic core is magnetized in the direction of 4-5 → 1, and the magnetic induction intensity is magnetized from + Bs to a certain magnetic induction intensity -B1 (-B1 is between 0 and -Bs). When the forward voltage VI is applied again until the magnetic core is saturated again, the magnetic core is magnetized in the direction of 1 → 2 → 3 → 4, and the magnetic flux density changes to B1 + Bs, which is larger than Bs. Obviously, the time for the magnetic core to reach saturation this time is longer than that for the first time to reach saturation, that is, the time for the magnetic core to maintain a high resistance state is prolonged.

Circuit design of magnetic amplifier scheme

The following circuit is the actual circuit obtained after formal project verification according to the scheme of Figure 4. This circuit is the auxiliary circuit part, the output is +5V, and the magnetic amplifier of cobalt-based amorphous material is selected. Vin is led out by the transformer secondary winding, and its voltage presents different types of periodic waveforms according to the circuit topology.

Waveform timing, as shown in Figure 7.

It is assumed that Vin is a square wave, and the working principle of this circuit is:

When Vin is at T3, due to the electromotive force induced by the transformer coil, vin is negative; if the PNP transistor is operating, VRST is positive, and thus VC is also positive, so that both ends of the magnetic amplifier are subjected to a forward voltage from VC to Vin, and the output of the transistor backpours current through the diode to the magnetic amplifier so that the magnetic amplifier is reset. When Vin goes to T1, the magnetic amplifier is in an unsaturated state, and according to the foregoing, the core impedance is very high, and the magnetic amplifier is equivalent to a switch shutdown, which continues until the magnetic amplifier is again saturated (T2 points). So we can get (Vrst-Vin-) (t1-t3) = Vin + (t2-t1)
Obviously, by controlling the value of \( V_{rst} \), it is possible to control the value of the reset voltsecond product, thereby determining the turn-off time of the magnetic amplifier. The change in the turn-off time of the magnetic amplifier determines the change in the duty cycle of \( V_i \). The duty cycle of \( V \) becomes smaller and the output voltage decreases. For this circuit, when the output voltage is greater than +5V (e.g. when the circuit is energized) the TIA31M is operated, the cathode and the anode thereof are on, and the base of the PNP triode is grounded through a resistance, at this time the triode is operated, when the circuit is operated to the T3 state, the process described above is repeated, the duty ratio of \( V_i \) is reduced, resulting in a reduction of the output voltage until the output voltage is less than +5V, at this time the TIA31M is not operated, thereby the triode is not operated, the duty ratio of \( V \) is equal to the duty ratio of the secondary output waveform of the transformer, the output voltage is increased, this stabilizes the output voltage at +5 V, and in the process most of the energy of the magnetic amplifier is returned to the circuit, which is conducive to improving efficiency.

5 Test Results

Take the T512 three-output DC/DC converter as an example, the output voltage is +5V, +12V. The product circuit is +12V output circuit as the main circuit, and +5V output circuit as the auxiliary circuit. The auxiliary circuit is fed back by the magnetic amplifier circuit. Fig. 8 is the structure block diagram of the product circuit.
The following is the MOSFET drain waveform at full load, rated input voltage, as shown in Figure 9.

It can be seen that the cycle is 3.6 us, the conduction time is 1.2 us, and the duty cycle is 33%.

Fig. 10 is a waveform of that front end of the magnetic amplify (I. E., Vn in FIG. 6).
As you can see, the period is 3.6 us, the conduction time is 1.2 us, and the duty cycle is 33%. Obviously, the period, conduction time, and duty cycle of the front end waveform of the magnetic amplifier are identical to those of the MOSFET drain, because the front end of the magnetic amplifier is connected to the secondary of the transformer, while the MOSFET drain is connected to the primary of the same transformer. Figure 11 shows the waveform of the rear end of the magnetic amplifier (Vc in Figure 6):

It can be seen that the cycle is still 3.6 us, but the conduction time is 1 us and the duty cycle is 27.8%, which shows that the operation of the magnetic amplifier circuit makes the duty cycle smaller and the output is stable at +5 V. The waveform of the auxiliary start-up voltage is shown.
As shown in the figure, the starting overshoot is 240mV, and then due to the role of the feedback circuit, the magnetic amplifier works, and the output is stable at +5V.

The main parameters of the measured results are shown in Table 1, and compared with similar products of IR Company.

Table 1 Test Results vs. IR ARM2812T

<table>
<thead>
<tr>
<th>特性</th>
<th>ARM2812T</th>
<th>TS12</th>
</tr>
</thead>
<tbody>
<tr>
<td>输出电压</td>
<td>5.00 ± 0.05</td>
<td>5.00 ± 0.02</td>
</tr>
<tr>
<td>输出电流</td>
<td>±12.00 ± 0.5</td>
<td>±12.00 ± 0.1</td>
</tr>
<tr>
<td>输出纹波电压（波峰～波谷）</td>
<td>±780</td>
<td>±625</td>
</tr>
<tr>
<td>电压调整范围</td>
<td>≤ ±100</td>
<td>≤ ±60</td>
</tr>
<tr>
<td>电压调整度</td>
<td>≤ ±15</td>
<td>≤ ±15</td>
</tr>
<tr>
<td>电流调整度</td>
<td>≤ ±60</td>
<td>≤ ±100</td>
</tr>
<tr>
<td>负载变化时输出电压变化</td>
<td>≤ ±180</td>
<td>≤ ±50</td>
</tr>
<tr>
<td>负载变化时输出电压恢复时间</td>
<td>≤ ±300</td>
<td>≤ ±120</td>
</tr>
<tr>
<td>输入电压波动时输出电压变化</td>
<td>1050</td>
<td>≤ ±300</td>
</tr>
<tr>
<td>输入电压波动时输出电压变化效率</td>
<td>≥ ±80</td>
<td>≥ ±80</td>
</tr>
<tr>
<td>短路功耗</td>
<td>≤ ±500</td>
<td>≤ ±60</td>
</tr>
<tr>
<td>启动过冲（峰值）</td>
<td>≤ ±1500</td>
<td>≤ ±600</td>
</tr>
<tr>
<td>启动延迟</td>
<td>≤ ±20</td>
<td>≤ ±10</td>
</tr>
<tr>
<td>交叉调整量</td>
<td>≤ ±500</td>
<td>≤ ±240</td>
</tr>
</tbody>
</table>

As can be seen from the above table, compared with similar products of IR company, the main electrical parameters of the product using magnetic amplifier scheme are equivalent, and some parameters are better.
6. Concluding remarks

In this paper, three kinds of three-way output power supply design schemes are proposed at first, in which the magnetic amplifier scheme can realize the miniaturization, high efficiency and stable output of the product better. Then, the characteristics and working principle of the magnetic amplifier are analyzed, and the working process of the magnetic amplifier is described in combination with the actual circuit. At last, the design scheme is verified through a specific project and the test data are given. The test result proves that the magnetic amplifier is feasible, reasonable and has certain superiority when it is applied to multi-way output power supply.