Noteworthy Non-linear Hysteresis Control Method
As a DC/DC Converter Control Method

Although the conventional mainstream DC/DC converter control methods were voltage control or current control, the non-linear hysteresis control method has gained the spotlight in recent years. Since 2005, FUJITSU has shipped more than 100 million DC/DC converter ICs that adopt the bottom detection comparator method (a type of hysteresis control method), mainly to the commercial market. This article introduces the bottom detection comparator method, focusing on its features.

Introduction

Process miniaturization has advanced in recent LSIs and the core voltage has been concurrently reduced, reaching a level of 1.0V or lower. It is 1.2V for the 90nm process which is the current mainstream and 0.7V to 1.0V for the 45nm process. The required voltage precision for these core voltages is extremely strict for DC/DC converters that supply power at ±10% or ±100mV or lower. Figure 1 presents the trends in core voltage with process miniaturization in leading-edge LSIs.

In general, the precision of the voltage supplied by DC/DC converters fluctuates by several percent due to the fluctuation in reference voltage and temperature characteristics. It may also fluctuate by as much as several dozen percent due to current consumption fluctuation (called load fluctuation) by the LSI, to which power is supplied by the converter. What is thus most important in supplying power to leading-edge LSIs with low voltage and large current is the transient response characteristics.
under load fluctuation in DC/DC converters.

While voltage control and current control are currently the most widely adopted DC/DC converter control methods, hysteresis control methods achieve the fastest transient response characteristics under load fluctuation. Hysteresis control methods are under the spotlight as a result of their performance improvements and the growing adoption of leading-edge processes in digital home appliances and game machines.

**Control by the Bottom Detection Comparator Method**

The bottom detection comparator method maintains the output voltage at a stable level by feeding back (FB) the ripple voltage waveforms generated in the output voltage and controlling the switching while constantly comparing the bottom value of the ripple voltage waveform with the reference voltage (Vref). For this reason, at FUJITSU this method is called the “bottom detection comparator method.”

*Figure 2* presents the block diagram for the bottom detection comparator method.

In contrast, the voltage control and current control methods maintain the output voltage at a stable level by switching control at the point of contact compared a triangular waveform (Ramp) corresponding to the internal clock with amplifying the difference voltage between the feedback voltage from the output voltage and reference voltage using an error amplifier.

*Figure 3* presents the block diagram for the voltage control method.

The greatest difference between the bottom detection comparator method (hereafter referred to as the comparator method) and the voltage/current control method is whether the switching is controlled one by one using a comparator or with a fixed frequency using an error amplifier.

**Product Features**

- **High-speed transient response characteristics under load fluctuation**

  The greatest feature of the comparator method is that it excels in transient response characteristics under load fluctuation. It is therefore possible to minimize the fluctuations in output voltage generated by load fluctuations. The reason for this lies in the “period” it takes for feedback control on the output voltage.

  Since the comparator method implements successive switching control with simple comparison at the comparator, as described previously, it has little feedback control delay. Also, it changes the off period depending on the changes in output voltage instead of operating at a fixed frequency.

  *Figure 4* presents the load fluctuation waveform for the comparator method.

  In contrast, the voltage control and current control methods generate feedback control delays by the following points and therefore have larger fluctuations in output voltage under load fluctuations compared to the comparator method in general.

  - Constant under CR by the phase compensation circuit
  - Frequency characteristics of the error amplifier
  - Internal clock timing

  *Figure 5* presents the load fluctuation waveform for the voltage/current control method.
There are of course several countermeasures against load fluctuation in the voltage control and current control methods. For instance, the oscillation frequency of the DC/DC converter is designed at high-speed to accelerate the switching timing. This is the simplest method that can be used to suppress load fluctuations. Designing the high oscillation frequency can also increase the switching loss and, as such, the efficiency characteristic, which is an important element for DC/DC converters, is sacrificed. The effect of switching noise must also be considered.

It is also possible to adjust the phase compensation circuit. Load fluctuations can be improved by increasing the error amplifier gain and frequency band (fco). However, this method requires mastery in power supply design technology and not everyone can employ it easily.

Although it is also possible to add an output smoothing capacitor, even the addition of a large-capacity capacitor may deliver little effect depending on its position and load current transition time (current through rate). Furthermore, it requires careful addition since it may cause a shift in the phase compensation circuit and lead to oscillation of the DC/DC converter output.

As discussed above, response characteristics can be improved somewhat by these countermeasures for the voltage/current control methods. However, the comparator method requires no such countermeasures and it can supply stable voltage with simple configuration thanks to its inherently good transient response characteristics.

**No phase compensation circuit required**

The phase compensation circuit required for the voltage/current control method is a circuit to adjust the phase delay of a feedback system and the gain of the error amplifier. If this circuit is adjusted incorrectly, unfavorable load fluctuation characteristics and oscillating output voltage may occur.

The comparator method uses no error amplifier and has little phase delay for feedback; it therefore requires no phase compensation circuit.

Our customers who have already adopted the comparator method have given us positive feedback. As described earlier, the phase compensation circuit requires mastery in technology and knowledge and it has been a source of concern to power supply engineers. In some cases, it required adjustment by preparing a special measurement environment or by trial and error for each power supply specification. This is because the output voltage may oscillate in the worst case scenario and have serious effects on the electrical device. FUJITSU has proposed optimal phase compensation circuit constants for power supply specifications and phase compensation circuit characteristic measurement support for mass production boards at the request of customers who adopt our voltage/current control method products.
In short, the comparator method contributes to convenience in power supply design and improved reliability because it requires no phase compensation circuit and has advantageous high-speed response characteristics.

**Secure on time switching control**

With the comparator method, switching control is implemented by fixing the on time instead of off time control. It is therefore possible to supply stable output voltage by securely controlling the on-pulse even under conditions with large input-output voltage difference including low voltage output.

With the voltage/current control method, the on time for switching is short under conditions with large input-output voltage difference because the on time is controlled by fixing the interval. However, it may fail to switch and lead to failure in maintaining the stability of the output voltage in the worst case if the on time is too short. In light of this, some products use many primary power supply outputs or many secondary or tertiary power supplies to prepare the voltage required for the LSI. The former leads to increased cost and the latter to increased power loss and lower energy-saving effects.

Cost reduction and energy saving have been demanded in recent devices. To deliver power supply circuits that address both of these demands, we recommend power supply ICs that adopt the comparator method.

**Figure 6** presents the conventional power supply configuration and the configuration that addresses both cost reduction and energy saving.

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**Technical Issues**

There are technical issues as well as advantages to the comparator method. One such issue is the necessity to purposely create ripple voltage in order to detect the bottom value for output ripple voltage. Because of this, its application had been restricted to capacitors with ESR elements in the output capacitors. This issue has been solved in our new product MB39A145, which is to be released following publication of this issue. It can be applied to any type of capacitor including ceramic capacitors.

Other issues also exist, including frequency fluctuation depending on conditions and symmetrical phase control and multi-phase control in multi-channel products. FUJITSU intends to solve these problems to fulfill market needs.

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**Figure 6** Conventional Power Supply Configuration and Configuration Addressing Both Cost Reduction and Energy Saving

![Diagram](image_url)

The comparator method is adopted to realize single power supply development for AC/DC and high efficiency by single conversion.