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Emulated Ripple Mode – The Future of Hysteretic Switch Mode Power Supplies

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Introduction

Hysteretic control in switch mode power supplies has been around for a very long time. It is a very simple control mechanism which requires little control circuitry and does not need to get compensated for stability like voltage mode control and current mode control regulators. Instead of an error amplifier, the hysteretic control uses a hysteretic comparator to check if the output voltage is out of regulation. Hysteretic mode control is very fast when it comes to transient response and is easy to implement with a low build cost, But there are some disadvantages that come with it, such as a changing switching frequency and input voltage changes as well. It is also required to provide the hysteretic comparator with enough ripple for proper operation. This minimum ripple requirement usually leads to a certain output voltage ripple which may not be acceptable in some applications. Advances in hysteretic mode control were made to eliminate these disadvantages. Constant On Time (COT) was introduced to avoid the wide change of switching frequency upon line variations and Emulated Ripple Mode (ERM) is the newest achievement to avoid the need for output voltage ripple.

How Does Hysteretic Mode Control Work?

Figure 1 shows the control schematic of hysteretic mode control. It is a very simple way to regulate a fixed output voltage. The necessary building blocks are a reference, a hysteretic comparator and a power stage which creates a pulse width modulation (PWM) duty-cycle based on the hysteretic comparator information.

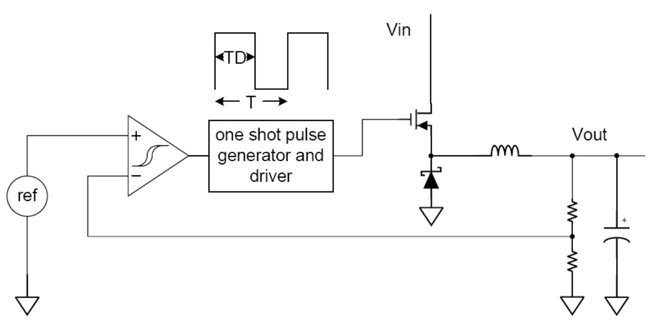

Figure 1. Pure Hysteretic Mode Control

When the output voltage is below the hysteretic comparators low threshold, an on time is initiated by the power stage. This on time is complete when the high threshold level of the hysteretic comparator is reached. By this the frequency is not constant, but dependent on how the output voltage changes during the on time as well as during the off time.

Hysteretic control does not require an internal oscillator. Switching frequency depends on the external components and operating conditions such as load current and line voltage since these parameters influence when the output voltage crosses the hysteretic comparator thresholds. The positive aspects of pure hysteretic mode control is the simple control concepts which requires little control circuitry. This makes hysteretic mode control solutions usually very low cost. Also hysteretic control is very fast and quickly adjusts for line and load transients. The disadvantage of such a control scheme is the varying switching frequency with the selection of power stage components, such as the inductor and output capacitor as well as the changing input voltage.

A second disadvantage is the requirement of ripple voltage at the input of the error comparator which is the feedback pin. If the ripple generated by the inductor current ripple and the output capacitor is phase shifted, the output voltage will not cross the hysteretic comparator thresholds in phase and the control scheme will not work smoothly. The result is burst mode operation and no continuous or clean switch node waveform.

When ceramic capacitors, which have very low ESR (equivalent series resistor), are used as output capacitors, the main voltage ripple generated is caused by the capacitance and not by the ESR of the component. This causes a sine wave like voltage ripple shifted by 90 degrees compared to a triangle like voltage ripple which is caused by an output capacitor with higher ESR. *Figure 2* shows the waveforms of output voltage ripple with a ceramic output capacitor and with an electrolytic capacitor.

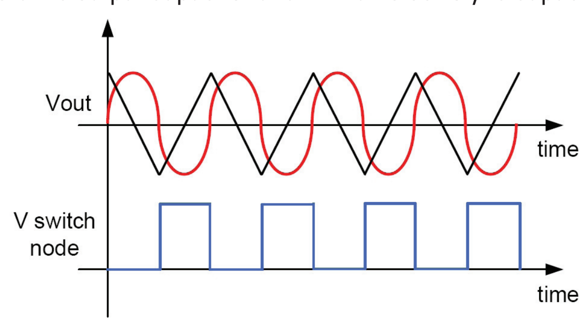

Figure 2. Output voltage ripple caused by a ceramic capacitor and a higher ESR capacitor

The black waveform is valid for capacitor types with higher ESR such as electrolytic capacitors. Here the output voltage ripple is in sync with the switch waveform. The red waveform shows the output ripple voltage with capacitors with very low ESR where the voltage ripple is not caused by the ESR but by the output capacitance itself. An example for a purely hysteretic mode controller is National Semiconductors LM3485.

The Benefit of Constant On Time (COT)

Constant On Time (COT) control is fixing the pure hysteretic mode character of changing switching frequency with line voltage. Especially in designs with a widely varying input voltage range, the switching frequency of heritage hysteretic mode power supplies would vary significantly. This yields quite a lot of problems. Possible EMI filtering in the system will have to be designed so that it will work for a wide range of frequencies. Also the power stage components and the input capacitor will have to be selected so that they are suitable for the wide range of operating frequency possible.

Constant On Time control sets a fixed on-time which is only influenced by the input voltage. The on-time becomes inversely proportional to the input voltage. With this feed-forward correction of line variations, the switching frequency will not have to change to keep the formula for duty-cycle, input voltage and output voltage satisfied ($D=V_{OUT}/V_{IN}$).

This concept is an excellent improvement also to voltage mode control regulators in regards to line regulation. In a pure voltage mode regulator, the duty-cycle is only corrected after a line transient once the effect of the varied input voltage has caused a change in the output voltage which is then corrected. In Constant On Time hysteretic mode concepts, line changes are taken into consideration before they even influence the output voltage.

An example for a Constant On Time regulator is National Semiconductors LM5010. *Figure 3* shows the diagram of a Constant On Time control scheme. The on timer determines an on time depending on V_{IN} and a frequency setting resistor between V_{IN} and the on timer function block.

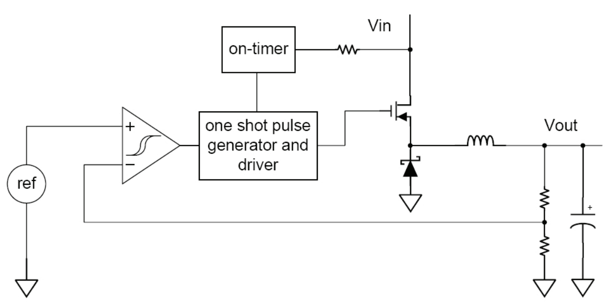

Figure 3. Constant On Time (COT) Control

The Benefit of Emulated Ripple Mode

Emulated Ripple Mode is the newest addition to the improvements for pure hysteretic control. This feature allows the use of ceramic output capacitors with very low ESR values with hysteretic mode control. The necessary ripple for the hysteretic comparator is now injected into the hysteretic comparator by sensing the inductor current during the off time. In typical Constant On Time regulators, the on time is fixed and only changes according to the input voltage. The critical threshold which defines the timing for stable operation is the low threshold of the hysteretic comparator. This threshold needs to be crossed with a signal in sync with the switching action. If an output capacitor with higher ESR is selected, its ripple on the feedback node can be used for the hysteretic comparator.

Instead of requiring the output voltage to drop, some off time low side current is sensed and injected into the error comparator. This gives the comparator a correctly timed signal to start a new cycle without the output voltage needing to see the output voltage ripple with the same timing as the switch node voltage.

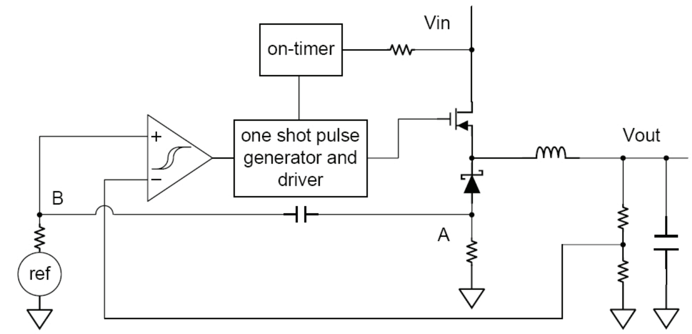

Figure 4. Emulated Ripple Mode (ERM) Control

Figure 4 shows a diagram of an Emulated Ripple Mode control loop added on to a Constant On Time control hysteretic mode power converter. An example for this new technology is National Semiconductors LM3100 family of synchronous buck regulators. It is a synchronous design compared to the regulator shown in *Figure 4.* Current is sensed during the off time at node A. This is very easily done in synchronous regulators where the low side switch is integrated into the IC. Then the off-time current information can easily be collected without the need for an external sense resistor or additional IC pins. This off-time current ramp information is in sync with the switch node and is AC coupled to node B by some small capacitance. The positive input of the hysteretic error comparator now sees the required ripple, which is in phase with the switch node voltage waveform. The negative input of the comparator will not need to provide this ripple information and by design the output capacitor may be a ceramic, organic or other very low ESR capacitor. Such a capacitor will make output voltages with very little ripple possible, even though a hysteretic mode concept with all its advantages is used.

Conclusion

Hysteretic mode control is a simple, low cost and easy to use control in power management. By using clever engineering such as Constant On Time and Emulated Ripple Control, the biggest disadvantages of hysteretic mode are eliminated. National Semiconductor's LM3100 family of products will switch at very constant switching frequencies even when the input voltage varies and it can be used with very low ESR output capacitors to provide ultra low output voltage ripple. All this coming from essentially a hysteretic mode control power supply. ■

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