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AN032

An Overview of AAM Mode

Advanced Asynchronous Modulation Application Note

ABSTRACT

The increasing demand for high-efficiency and low-power electronics has resulted in rising demand for power converters—especially DC-DC converters—that operate with pulse-frequency modulation (PFM) at light-load currents, and pulse-width modulation (PWM) at heavier current loads. This application note introduces MPS's proprietary Advanced Asynchronous Modulation (AAM) technology, and includes sample designs.

Figure 1 shows a typical block diagram of a converter with AAM mode. The block diagram is almost the same as a step-down converter with a PWM switching frequency of 500kHz, except that under light-load conditions the voltage at the AAM pin sets the PFM mode operation and its load range.

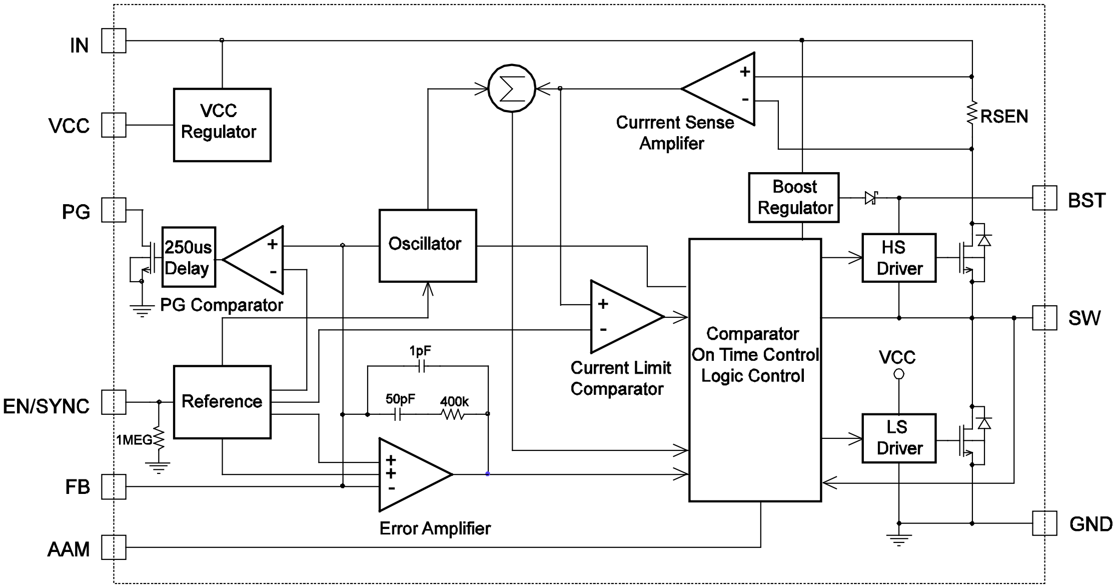


Figure 1: Functional Block Diagram

INTRODUCTION TO AAM CONTROL

The AAM is effectively a function of the output current where the output current (as sensed through a resistor) is compared against a level set by a voltage applied to the AAM pin: The applied voltage determines the switching points between PFM and PWM modes. A user can choose an appropriate transition point that balances between multiple parameters—including switching efficiency, transient response, power consumption, and output ripple—by setting the AAM voltage (V_{AAM}) through an external resistor divider.

Figure 2 shows the simplified control logic, and **Figure 3** shows the signal diagrams. When the clock goes high and V_{COMP} is greater than V_{AAM}, the high-side switch (HS-FET, "HS" in the diagrams) turns on, $I_{inductor}$ (as measured from a sense resistor) ramps up until it reaches the COMP level. When $I_{inductor}$ reaches COMP, the HS-FET turns off and the low-side MOSFET (LS-FET) turns on to drop $I_{inductor}$ below zero when the LS-FET turns off. The internal clock resets every time V_{COMP} exceeds V_{AAM} and this period between resets determines the length of the next clock cycle. If the DC value of V_{COMP} is less than V_{AAM} and V_{FB} is less than V_{ref}, V_{COMP} ramps up until it exceeds V_{AAM}: During this time, the converter can skip some pulses for PFM mode. When the load increases and the DC value of V_{COMP} is higher than V_{AAM}, the operation mode is discontinuous conduction mode (DCM) or continuous conduction mode (CCM), which has a fixed switching frequency.

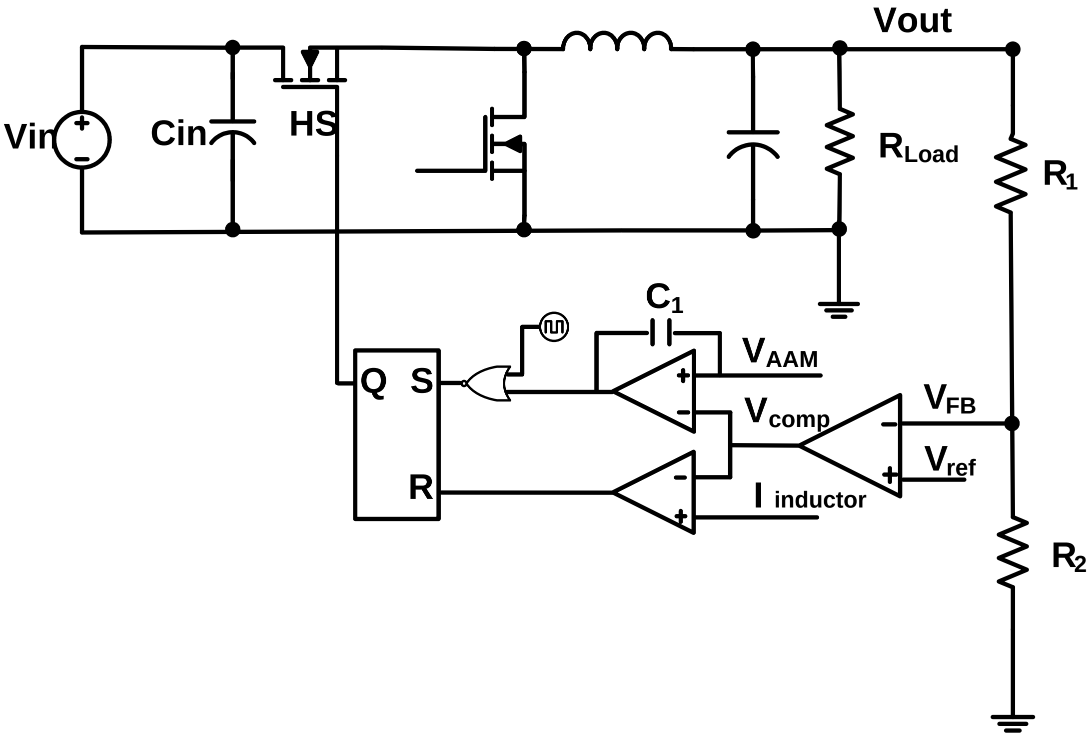
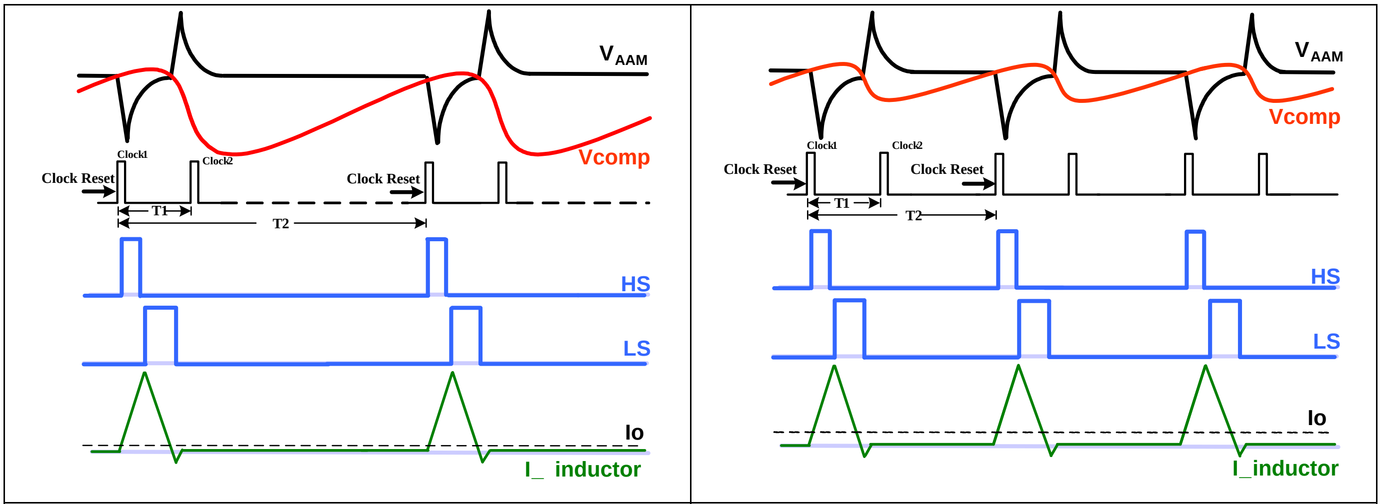
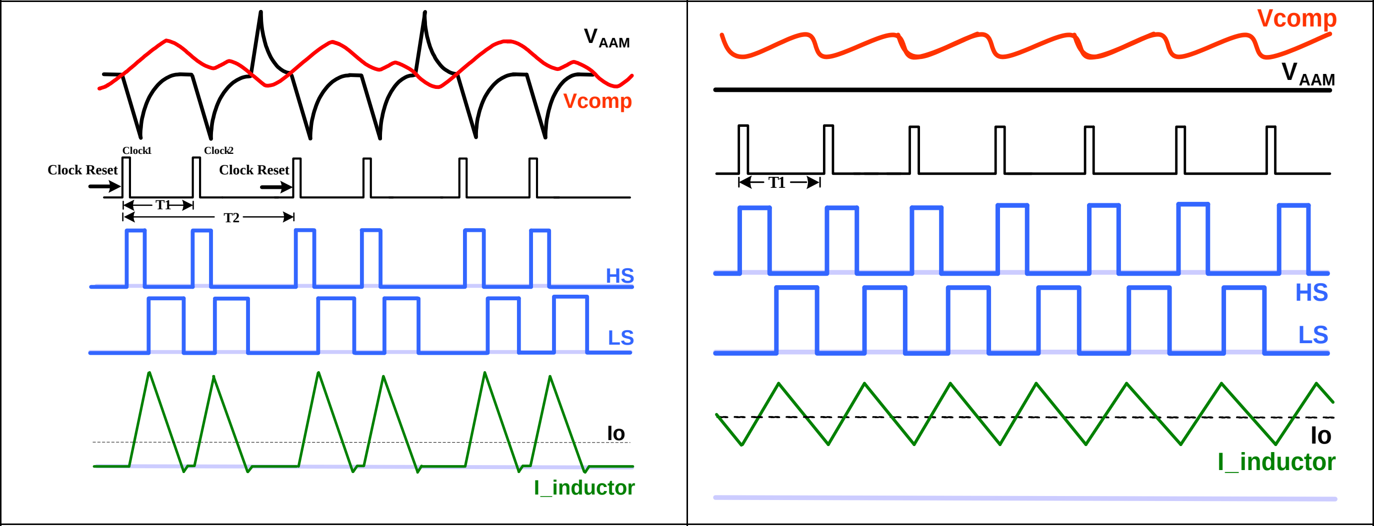


Figure 2: Simplified PFM Control Logic

The capacitor C1 between the AAM node and the AAM comparator output adds an AC hysteretic for the comparator logic: When V_{COMP} crosses above V_{AAM}, the output of the AAM comparator drops to zero and C1 causes V_{AAM} to drop; when V_{COMP} crosses below V_{AAM}, V_{AAM} rises. This AC hysteretic is quite useful for noise immunity. It avoids multiple V_{COMP} and V_{AAM} crossings within a short time, which would cause an ultra-high–switching frequency.



(a) PFM Under Extreme Light Load **(b) PFM Under Light Load**



(c) PFM Under Heavy Load **(d) CCM Under Heavy Load**

Figure 3: PFM and CCM Signal Diagrams

The switching frequency increases as the load increases as shown in **Figure 3**(a), (b) and (c), where T1 is the fixed switching period caused by normal 500kHz clock, and T2 is the burst switching period caused by V_{COMP} and V_{AAM}.

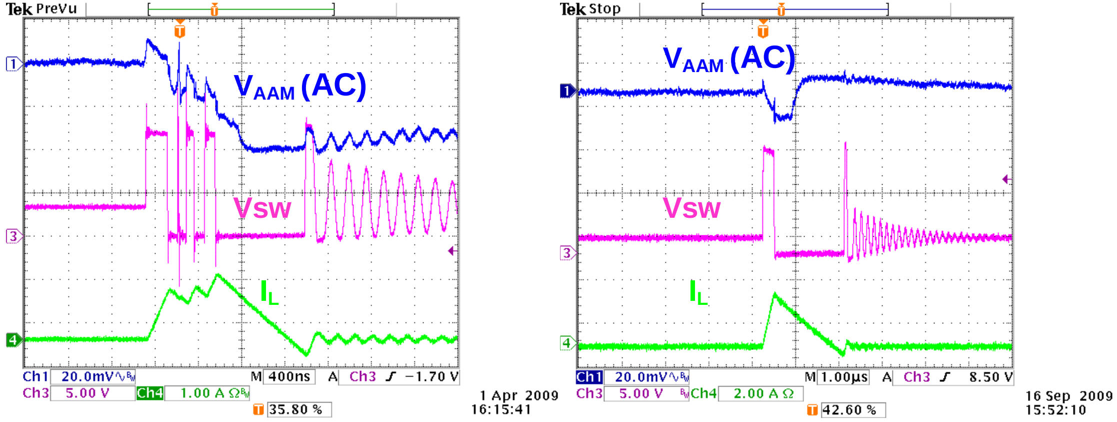
Under extremely light loads in PFM mode, as shown in **Figure 3**(a), the DC value of V_{COMP} is very low and the V_{COMP} value swings dramatically. After V_{COMP} crosses above V_{AAM}, V_{COMP} falls sharply and the duration that $V_{COMP} < V_{AAM}$ is very long, during which the converter skips T1 pulses and the switching frequency is very low.

Under light-load, as shown in **Figure 3**(b), the DC value of V_{COMP} increases over the value under extremely light loads, and the V_{COMP} swing is smaller. After V_{COMP} increases above V_{AAM}, V_{COMP} decreases more slowly than under the previous case. Because the duration of $V_{COMP} < V_{AAM}$ is shorter, the converter skips fewer T1 pulses, which results in a higher switching frequency.

As shown in **Figure 3**(c), as the load increases to the medium load range, the DC value of V_{COMP} increases, and the duration that $V_{COMP} > V_{AAM}$ is longer. As a result, the HS-FET turns on at the first clock reset. The HS-FET is turned on at the fixed 500kHz clock, but the inductor current frequency switches twice as fast, and the output voltage ripple is larger than under light-load. As the inductor current increases, the two periods in the current switching signals—T1 which is equal to the fixed switching period of CCM mode, and T2 which is the burst period—equalize, and T1 pulses until the system enters into DCM or CCM mode completely. When in DCM or CCM mode, only T1 exists as **Figure 3**(d) shows.

The AAM hysteretic mode helps to reduce noise at the AAM node that could cause abnormal pulse groups if the noise occurs as V_{COMP} rises above V_{AAM}, as shown in Figure 4(a). The effects of the AAM hysteretic mode can be seen in Figure 4(b).

Test Conditions: V_{IN}=12V, Vo=1.8V, Io=0A,



(a) Without AAM AC Hysteretic

(b) With AAM AC Hysteretic

Figure 4: AAM AC Hysteretic Can Avoid Noise Influence on AAM Voltage

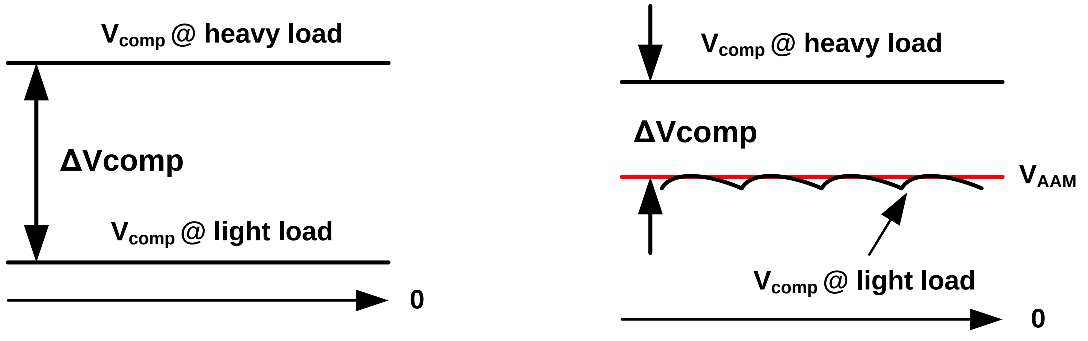
For PFM control logic—alternatively, constant-peak–current control—V_{COMP} is clamped by V_{AAM}, so therefore the peak of $I_{inductor}$ is also clamped by V_{AAM}. For other control methods, V_{COMP} increase as the load current increases: For constant-peak–current control under light load as the load current increases, V_{COMP} switches around V_{AAM}, and the converter operates in PFM mode. As the load current increases and V_{COMP} rises above V_{AAM}, and the converter operates in DCM and CCM modes. The switching frequency is fixed to around 500 kHz.

MERITS OF AAM CONTROL SCHEME

There are several advantages to constant-peak–current control.

1. LOAD TRANSIENT RESPONSE CAN BE IMPROVED

For constant-peak–current control, $V_{\mathbf{COMP}}$ is clamped by $V_{\mathbf{AAM}}$, and the $V_{\mathbf{COMP}}$ gap between light load and heavy load is much smaller for AAM control than compared to traditional peak-current mode (PCM) control, as shown in Figure 5. When the load current shifts from light load to heavy load, $V_{\mathbf{COMP}}$ needs to change $\Delta V_{\mathbf{COMP}}$; if the slew rate of $V_{\mathbf{COMP}}$ remains the same, $\Delta V_{\mathbf{COMP}}$ stays small and the loop response speeds up for a faster transient response than with traditional peak-current control.



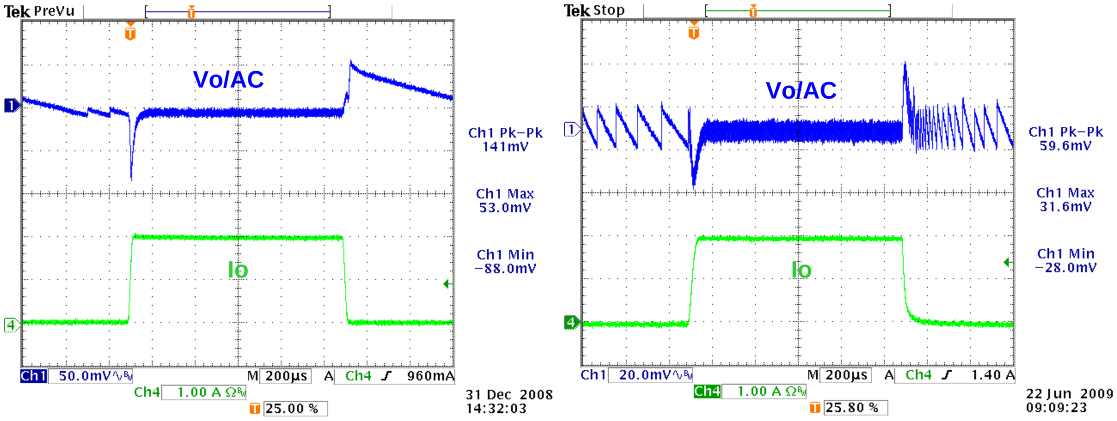
A) Traditional PCM control

B) Constant peak current control

Figure 5: ΔVCOMP for Different Control Method

Figure 6 shows load transient test waveforms for different control methods under the same conditions. The plotted signals clearly show that the converter with AAM has much better load transient performance; the peak to peak ripple is 50% smaller than that of traditional PCM control.

Test condition:Vin=19, Vo=1.8V, Io=0~2A, slew rate:2.5A/us



A) Traditional peak current control

B) Constant peak current control

Figure 6: Load Transient Response Comparisons

2. EASILY-OPTIMIZABLE LIGHT-LOAD EFFICIENCY

Generally speaking, there are two types of power loss for the internal power MOSFET: DC loss, and AC loss. The DC loss is determined by the R_{DSon} of the MOSFETs. The AC loss results from switching losses and gate-driver losses that are proportional to the switching frequency. To optimize efficiency, DC loss dominates the efficiency during heavy-load conditions, and AC loss dominates at light-load conditions. When in PFM mode whose range is set by AAM voltage, the frequency decreases and the efficiency can be improved at light load.

Based on previous analysis, higher V_{AAM} equates to higher peak current. This means that more power is transmitted to the output during one HS-FET turn-on pulse. As a result, as the switching frequency decreases the switching losses decrease during light load. Figure 7 shows that efficiency improves with higher V_{AAM} given the same power stage parameters.

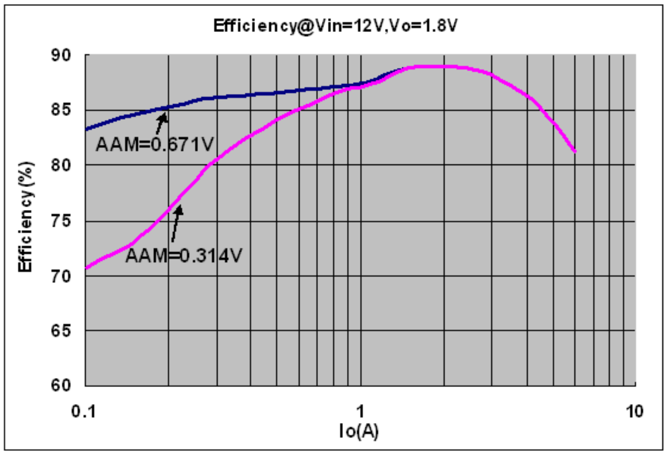


Figure 7: Efficiency Curves for Different V_{AAM}

Selecting the AAM voltage

As Figure 8 shows, V_{AAM} can programmed with a resistor divider and V_{CC}(5V). The two resistors are the only external components needed to set the AAM.

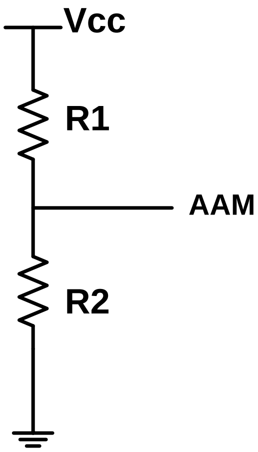


Figure 8: AAM Network

V_{AAM} sets the peak inductor current and V_{COMP} during light load, and sets the transition point from PFM to DCM/CCM; chose a voltage that provides the best balance between efficiency, ripple, and transient response. As discussed previously, if the V_{AAM} is set low, then output ripple improves but the efficiency at PFM mode and transient performance suffers: If the V_{AAM} is set higher, then the efficiency at PFM mode and transient performance improve, but the output ripple increases.

Normally, the converter has three operating modes for the entire load range: PFM, DCM, CCM. The boundary between DCM and CCM (critical CCM) is where the inductor ripple minimum is zero as Figure 9 shows:

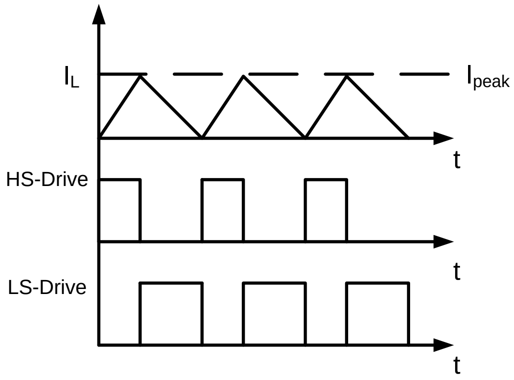


Figure 9: Critical CCM

When the input voltage, output voltage and inductance are all fixed, the compensation voltage in critical mode ($V_{Critical\_COMP}$) can be calculated as:

$$I_{peak} = \frac{V_{OUT}(V_{IN} - V_{OUT})}{V_{IN} \cdot L \cdot f_s} \tag{1}$$

$$V_{Critical\_COMP} = \frac{I_{peak}}{G_{CS}} + V_{slope} \tag{2}$$

Where G_{cs} is almost equal to 5, V_{slope} is the slope compensation voltage which is calculated by (3)

$$V_{slope} = 0.6D \tag{3}$$

Where D is the duty cycle.

If V_{AAM} is higher than $V_{Critical\_COMP}$, the converter moves from PFM to CCM mode directly when V_{COMP} ramps up high and isn't clamped by $V_{AAM.}$ The DCM mode is eliminated.

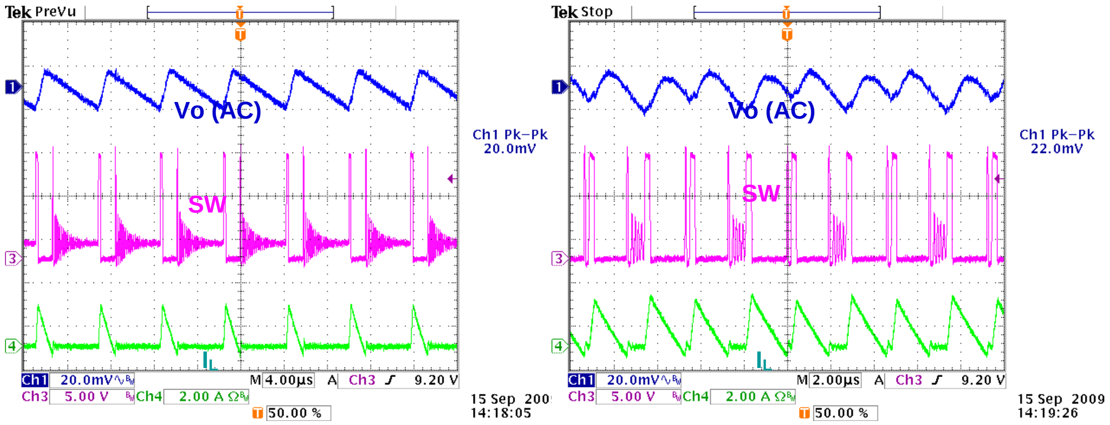
If V_{AAM} is set lower than $V_{Critical\_COMP}$, then there is zone of DCM when V_{COMP} is higher than V_{AAM} and lower than $V_{Critical\_COMP}$: A higher V_{AAM} causes higher efficiency in light load but larger output ripple.

The $V_{Critical\_COMP}$ is the key point to set $V_{AAM,}$ there are two ways to set $V_{AAM:}$

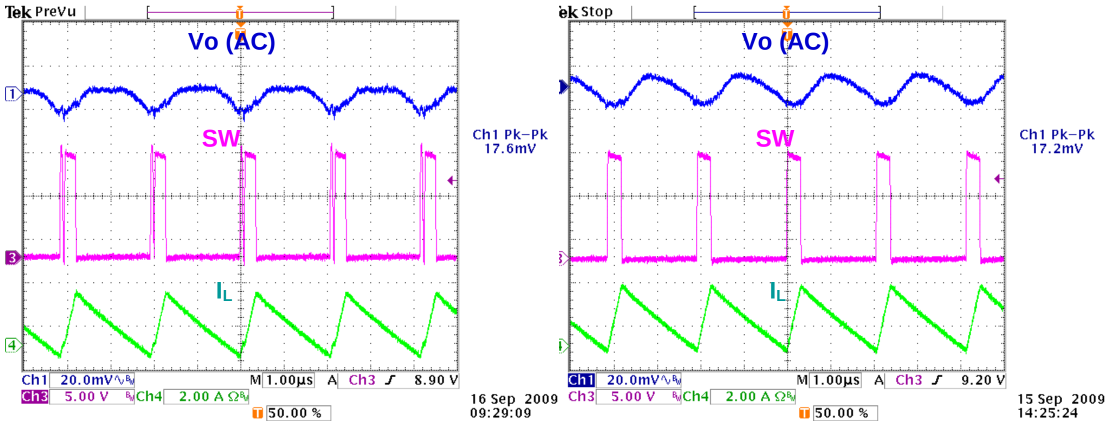
1. SETTING APPROPRIATE V_{AAM}: $V_{AAM} \leq V_{CRITICAL\_COMP}$

Setting V_{AAM} slight lower than $V_{Critical\_COMP}$, the converter has three operating modes in the full load range and the mode transition is smooth as Figure 10 shows. As previously discussed, as the load increases into the medium load range, the output ripple increases from the shift in the switching periods, T1 and T2 from Figure 4(c).

As the gap is between V_{AAM} and $V_{Critical\_COMP}$ shrinks, the DCM range narrows. To improve efficiency with reasonable ripple, set V_{AAM} close to $V_{Critical\_COMP}$.



(a) PFM Mode at 0.2A (b) PFM Mode at 0.7A



(c) DCM Mode at 1.1A (d) CCM Mode at 1.2A

Figure 10: Waveforms when $V_{AAM} \leq V_{Critical\_COMP}$; Test conditions: V_{AAM} =0.555V, $V_{Critical\_comp}$ =0.618V

2. SETTING V_{AAM} HIGHER: $V_{AAM} > V_{CRITICAL\_COMP}$

Setting V_{AAM} higher than $V_{Critical\_COMP}$ eliminates the DCM operation: The advantage of this setting is that light load efficiency is improved as shown in Figure 11.

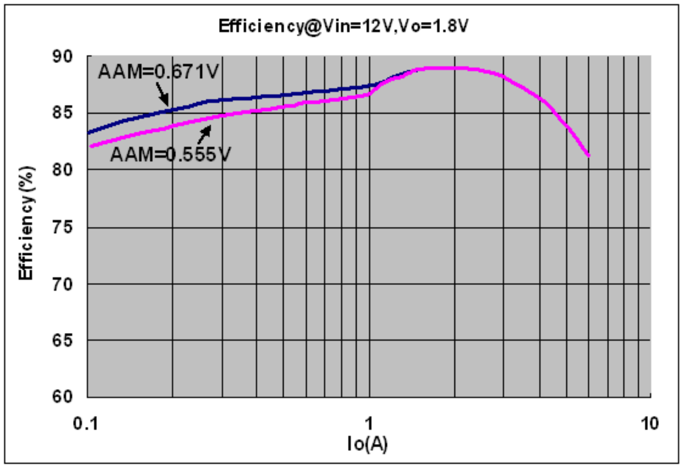
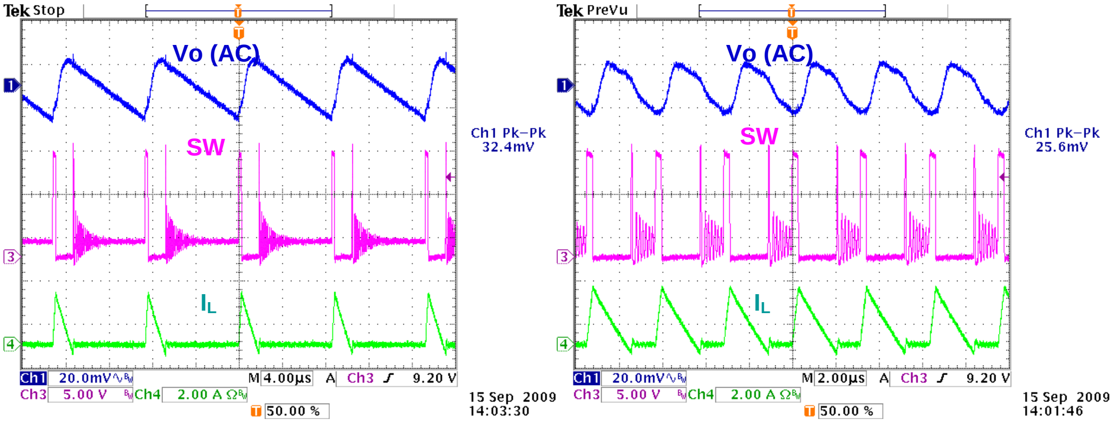


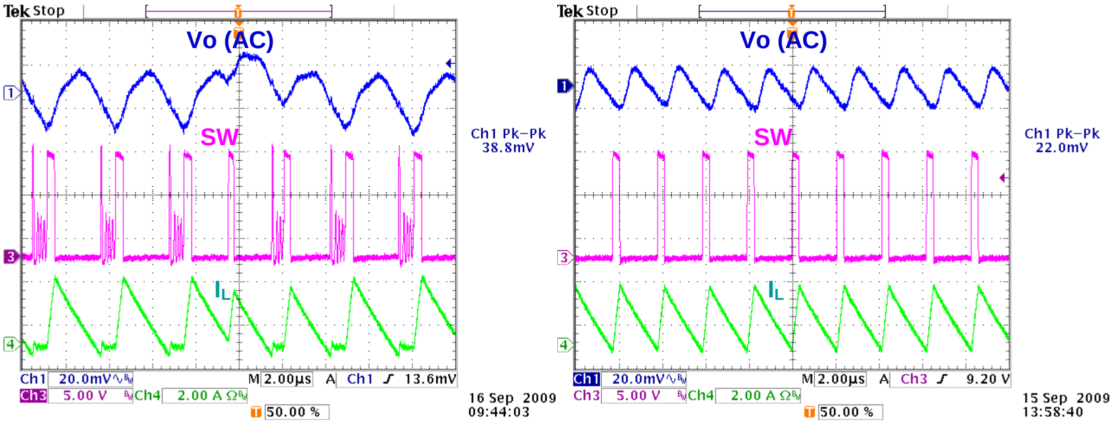
Figure 11: Efficiency comparisons with different V_{AAM}; $V_{Critical\_COMP}$= 0.618V.

As a trade off, the output ripple increases during light- and medium-load as shown in Figure 12. Setting V_{AAM}>$V_{Critical\_COMP}$ results in more power transferred to the output during one duty cycle and a lower switching frequency, resulting in a larger output ripple. This situation worsens at medium load.

Test conditions: V_{AAM} =0.671V,$V_{Critical\_comp}$ =0.618V



(a) PFM Mode at 0.2A (b) PFM Mode at 0.7A



(c) PFM Mode at 1.1A (d) CCM Mode at 1.2A

Figure 12: Waveforms for V_{AAM}>$V_{Critical\_COMP}$

CONCLUSION

A converter with AAM enhances overall efficiency, especially at light load. Compared to traditional peak-current control, constant-peak–current control with AAM has the following advantages:

- Easy-to-optimize light-load efficiency
- Fast load-transient response

A converter with AAM mode requires minimal external component and its performance is ideal for applications such as Notebooks/Netbooks computers, networking systems, set-top boxes, flat-panel televisions, and monitors. The following table includes representative products with AAM mode:

Part Number	Vin (V)	Iout (A)	I_{SW} Limit (Typ) (A)	I_Q (Typ) (mA)	V_{FB} (V)	Switching Freq (kHz)	Soft Start	External Sync	Power Good	Pkg
NB634	4.5-24	5	7	1	0.805	500	Int.	Yes	Yes	3x4QFN14
NB637	7-24		9	1	0.805	500	Int.	Yes	Yes	3x4QFN14
MP1494*	4-16	2		1	0.8	500	Int.	Yes	No	TSOT-23-8
MP1495*	4-16	3		1	0.8	500	Int.	Yes	No	TSOT-23-8
MP28251*										

*: not released