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.

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.

![Simplified PFM Control Logic](image)

**Figure 2: Simplified PFM Control Logic**

The capacitor \( C_1 \) 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 \( C_1 \) 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.
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 VCOMP and VAAM.

Under extremely light loads in PFM mode, as shown in Figure 3(a), the DC value of VCOMP is very low and the VCOMP value swings dramatically. After VCOMP crosses above VAAM, VCOMP falls sharply and the duration that VCOMP < VAAM 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 VCOMP increases over the value under extremely light loads, and the VCOMP swing is smaller. After VCOMP increases above VAAM, VCOMP decreases more slowly than under the previous case. Because the duration of VCOMP < VAAM 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 VCOMP increases, and the duration that VCOMP > VAAM 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).

![Figure 4: AAM AC Hysteretic Can Avoid Noise Influence on AAM Voltage](image)

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, $V_{COMP}$ is clamped by $V_{AAM}$, and the $V_{COMP}$ 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, $V_{COMP}$ needs to change $\Delta V_{COMP}$; if the slew rate of $V_{COMP}$ remains the same, $\Delta V_{COMP}$ stays small and the loop response speeds up for a faster transient response than with traditional peak-current control.
AN032-AN OVERVIEW OF AAM MODE

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

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.
Selecting the AAM voltage

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

$V_{AAM}$ sets the peak inductor current and $V_{COMP}$ during light load, and sets the transition point from PFM to DCM/CCM; choose 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:
When the input voltage, output voltage and inductance are all fixed, the compensation voltage in critical mode ($V_{\text{Critical\_COMP}}$) can be calculated as:

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

$$V_{\text{Critical\_COMP}} = \frac{I_{\text{peak}}}{G_{CS}} + V_{\text{slope}}$$  \hspace{1cm} (2)

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

$$V_{\text{slope}} = 0.6D$$  \hspace{1cm} (3)

Where $D$ is the duty cycle.

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

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

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

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

Setting $V_{AAM}$ slight lower than $V_{\text{Critical\_COMP}}$, 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 $V_{\text{Critical\_COMP}}$ shrinks, the DCM range narrows. To improve efficiency with reasonable ripple, set $V_{AAM}$ close to $V_{\text{Critical\_COMP}}$. 

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{figure9.png}
\caption{Critical CCM}
\end{figure}
Figure 10: Waveforms when $V_{AAM} \leq V_{\text{Critical\_COMP}}$; Test conditions: $V_{AAM} = 0.555V$, $V_{\text{Critical\_comp}} = 0.618V$
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 $V_{AAM}$; $V_{CRITICAL\_COMP} = 0.618V$.](image)

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:

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Vin (V)</th>
<th>Iout (A)</th>
<th>(I_{SW}) Limit (Typ) (A)</th>
<th>(I_2) (Typ) (mA)</th>
<th>(V_{FB}) (V)</th>
<th>Switching Freq (kHz)</th>
<th>Soft Start</th>
<th>External Sync</th>
<th>Power Good</th>
<th>Pkg</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB634</td>
<td>4.5-24</td>
<td>5</td>
<td>7</td>
<td>1</td>
<td>0.805</td>
<td>500</td>
<td>Int.</td>
<td>Yes</td>
<td>Yes</td>
<td>3x4QFN14</td>
</tr>
<tr>
<td>NB637</td>
<td>7-24</td>
<td></td>
<td></td>
<td>1</td>
<td>0.805</td>
<td>500</td>
<td>Int.</td>
<td>Yes</td>
<td>Yes</td>
<td>3x4QFN14</td>
</tr>
<tr>
<td>MP1494*</td>
<td>4-16</td>
<td>2</td>
<td></td>
<td>1</td>
<td>0.8</td>
<td>500</td>
<td>Int.</td>
<td>Yes</td>
<td>No</td>
<td>TSOT-23-8</td>
</tr>
<tr>
<td>MP1495*</td>
<td>4-16</td>
<td>3</td>
<td></td>
<td>1</td>
<td>0.8</td>
<td>500</td>
<td>Int.</td>
<td>Yes</td>
<td>No</td>
<td>TSOT-23-8</td>
</tr>
<tr>
<td>MP28251*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*: not released

NOTICE: The information in this document is subject to change without notice. Users should warrant and guarantee that third party Intellectual Property rights are not infringed upon when integrating MPS products into any application. MPS will not assume any legal responsibility for any said applications.