Not Recommended For New Designs

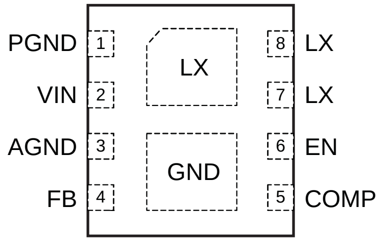
Replacement Part: AOZ6605PI

Ordering Information

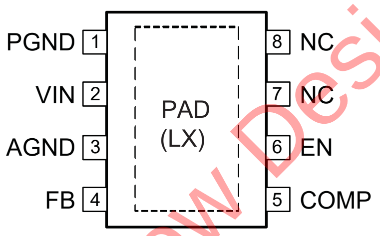
Part Number	Ambient Temperature Range	Package	Environmental
AOZ1036DI	-40°C to +85°C	5x4 DFN-8	Green Product
AOZ1036PI		Exposed Pad SO-8	

AOS Green Products use reduced levels of Halogens, and are also RoHS compliant. Please visit www.aosmd.com/web/quality/rohs_compliant.jsp for additional information.

Pin Configuration



5x4 DFN-8
(Top View)

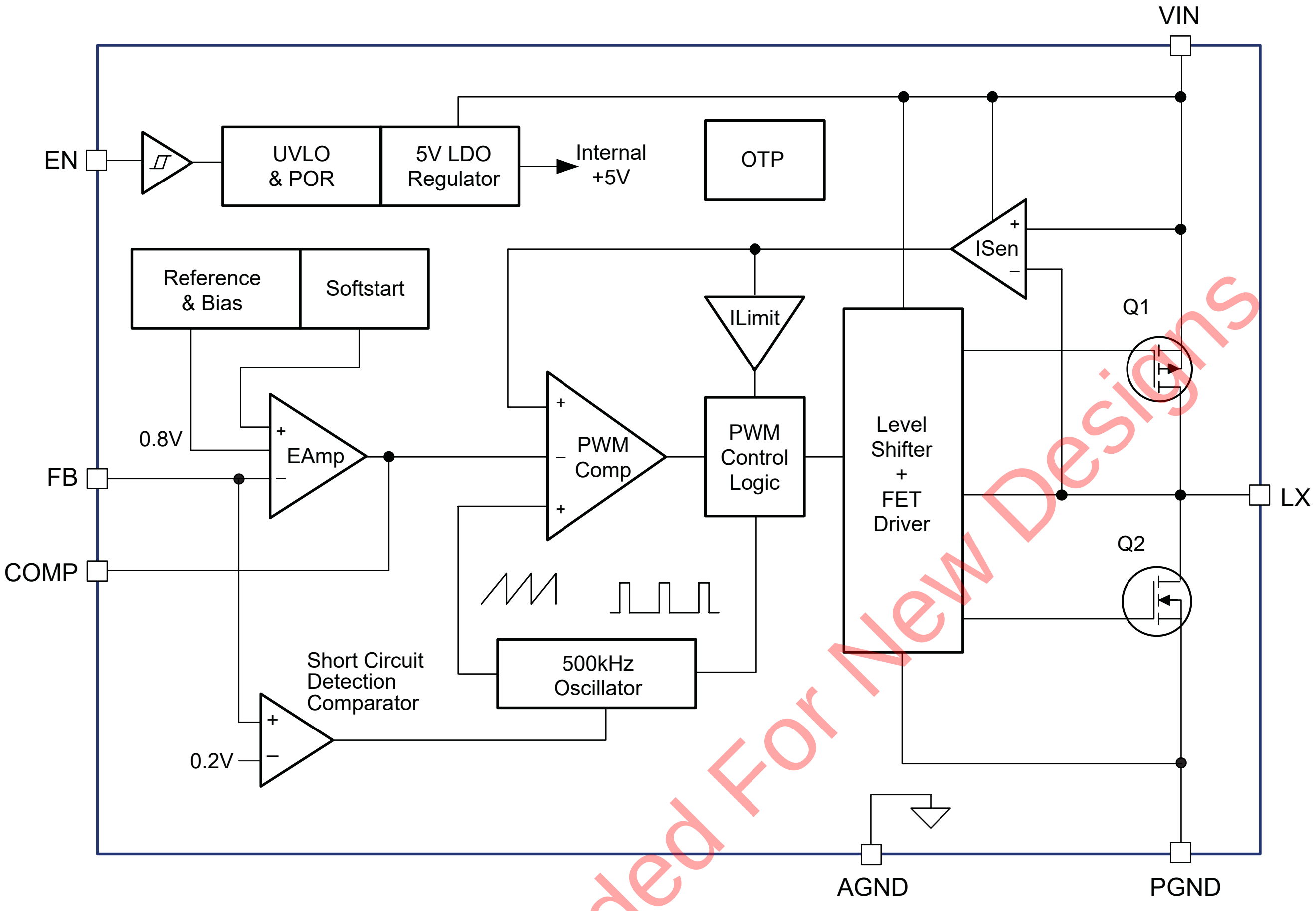


Exposed Pad SO-8
(Top View)

Pin Description

Pin Number		Pin Name	Pin Function
5x4 DFN-8	Exposed Pad SO-8		
1	1	PGND	Power ground. Electrically needs to be connected to AGND.
2	2	VIN	Supply voltage input. When VIN rises above the UVLO threshold the device starts up.
3	3	AGND	Reference connection for controller section. Also used as thermal connection for controller section. Electrically needs to be connected to PGND.
4	4	FB	The FB pin is used to determine the output voltage via a resistor divider between the output and GND.
5	5	COMP	External loop compensation pin.
6	6	EN	The enable pin is active high. Connect it to VIN if not used and do not leave it open.
7, 8	Pad	LX	PWM output connection to inductor.
	7, 8	NC	No Connect. Pin 7 and 8 are not internally connected. Connect these two pins externally to LX and use them for better thermal performance.

Block Diagram



Absolute Maximum Ratings

Exceeding the Absolute Maximum ratings may damage the device.

Parameter	Rating
Supply Voltage (V_{IN})	20V
LX to AGND	-0.7V to V_{IN}+0.3V
LX to AGND	23V (<50ns)
EN to AGND	-0.3V to V_{IN}+0.3V
FB to AGND	-0.3V to 6V
COMP to AGND	-0.3V to 6V
PGND to AGND	-0.3V to +0.3V
Junction Temperature (T_J)	+150°C
Storage Temperature (T_S)	-65°C to +150°C
ESD Rating(1)	2.0kV

Note:

1. Devices are inherently ESD sensitive, handling precautions are required. Human body model rating: 1.5kΩ in series with 100pF.

Recommended Operating Conditions

The device is not guaranteed to operate beyond the Maximum Recommended Operating Conditions.

Parameter	Rating
Supply Voltage (V_{IN})	4.5V to 18V
Output Voltage Range	0.8V to V_{IN}
Ambient Temperature (T_A)	-40°C to +85°C
Package Thermal Resistance (Θ_{JA}) 5x4 DFN-8 Exposed Pad SO-8	 50°C/W 50°C/W

Note:

2. The value of Θ_{JA} is measured with the device mounted on 1-in^2 FR-4 board with 2oz. Copper, in a still air environment with T_A = 25°C. The value in any given application depends on the user's specific board design.

Electrical Characteristics

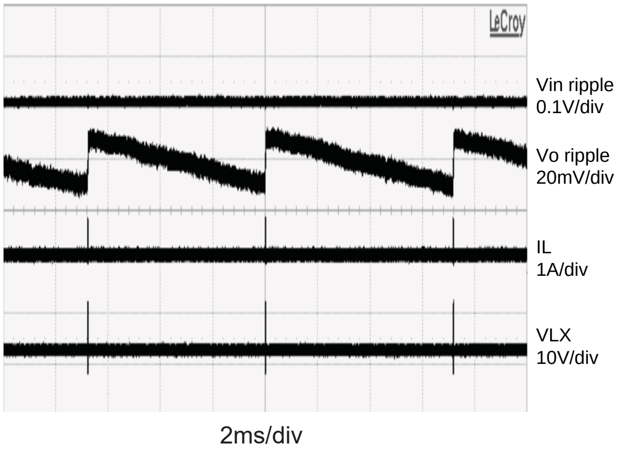
T_A = 25°C, V_{IN} = V_{EN} = 12V, V_{OUT} = 3.3V unless otherwise specified. Specifications in **BOLD** indicate a temperature range of -40°C to +85°C.

Symbol	Parameter	Conditions	Min.	Typ.	Max	Units
V_{IN}	Supply Voltage		**4.5**		**18**	V
V_{UVLO}	Input Under-voltage Lockout Threshold	V_{IN} rising V_{IN} falling		**4.1** **3.7**		V V
I_{IN}	Supply Current (Quiescent)	I_{OUT} = 0, VFB = 1.2V, V_{EN} >1.2V		**1.6**	**2.5**	mA
I_{OFF}	Shutdown Supply Current	V_{EN} = 0V		**1**	**10**	μA
V_{FB}	Feedback Voltage	T_A = 25°C	0.788	0.8	0.812	V
	Load Regulation			0.5		%
	Line Regulation			1		%
I_{FB}	Feedback Voltage Input Current				200	nA
V_{EN}	EN input threshold	Off threshold On threshold	 **2**		**0.6**	V V
V_{HYS}	EN Input hysteresis			**100**		mV
MODULATOR						
f_O	Frequency		400	500	600	kHz
D_{MAX}	Maximum Duty Cycle		100			%
T_{on_min}	Minimum On Time			150		ns
	Error Amplifier Voltage Gain			500		V / V
	Error Amplifier Transconductance			200		μA / V
PROTECTION						
I_{LIM}	Current Limit		5.8	6.5		A
	Over-temperature Shutdown Limit	T_J rising T_J falling		150 100		°C °C
t_{SS}	Soft Start Interval			3		ms
OUTPUT STAGE						
	High-side Switch On-resistance	V_{IN} = 12V V_{IN} = 5V		55 75		mΩ
	Low-side Switch On-resistance	V_{IN} = 12V V_{IN} = 5V		19 23		mΩ

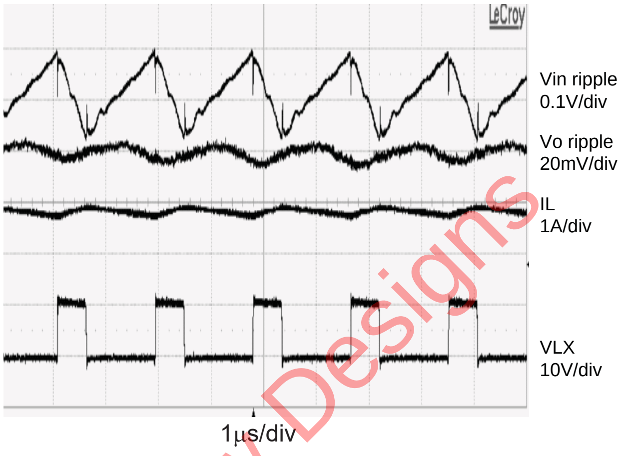
Typical Performance Characteristics

Circuit of Figure 1. $T_A = 25°C$, $V_{IN} = V_{EN} = 12V$, $V_{OUT} = 3.3V$ unless otherwise specified.

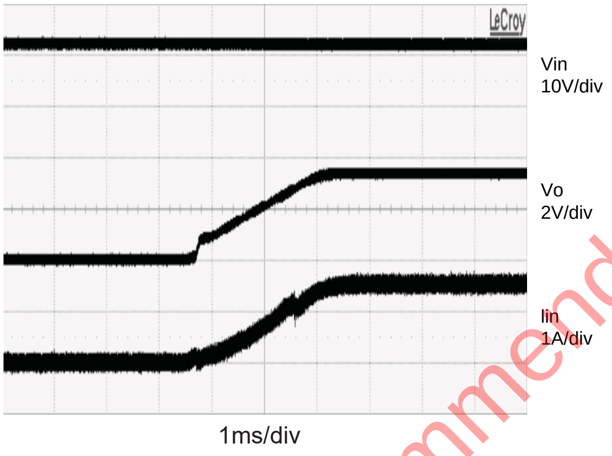
Light Load Operation



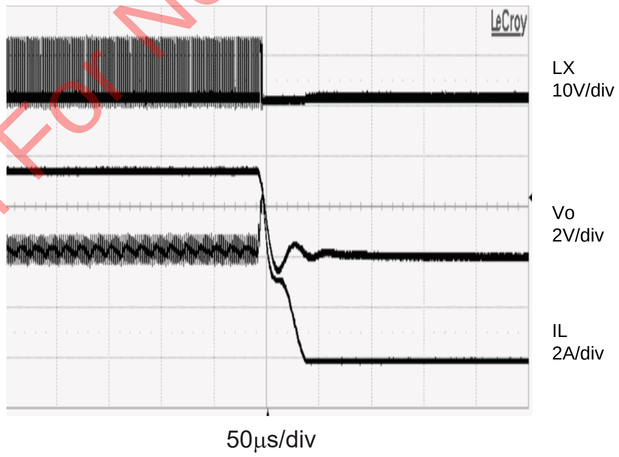
Full Load (CCM) Operation



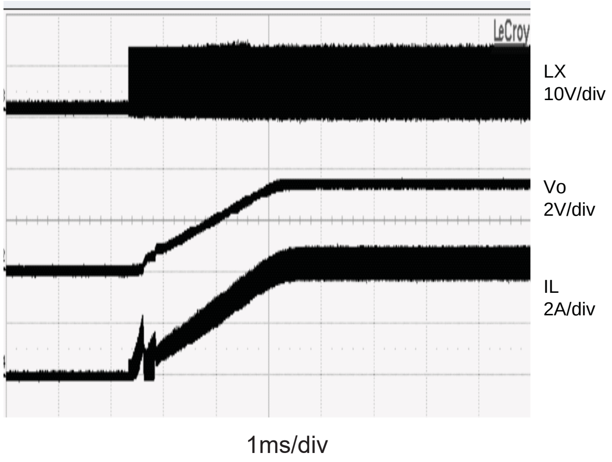
Start Up to Full Load



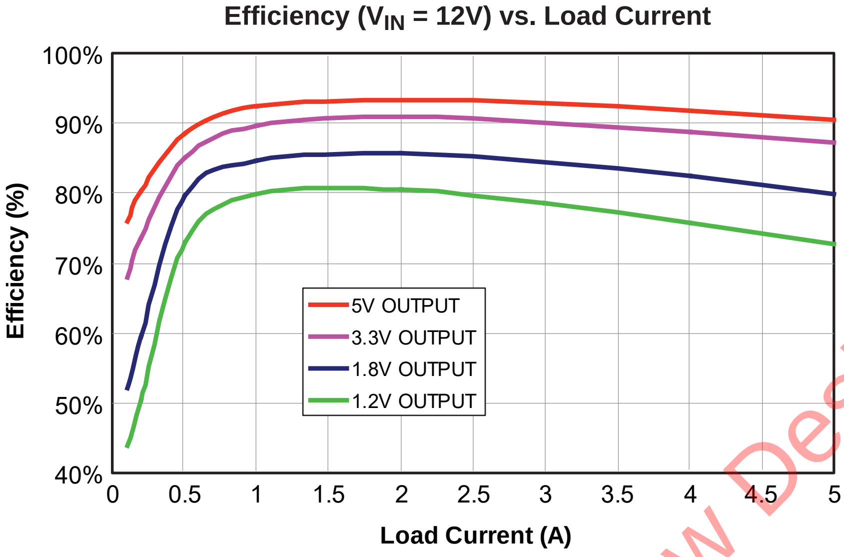
Short Circuit Protection

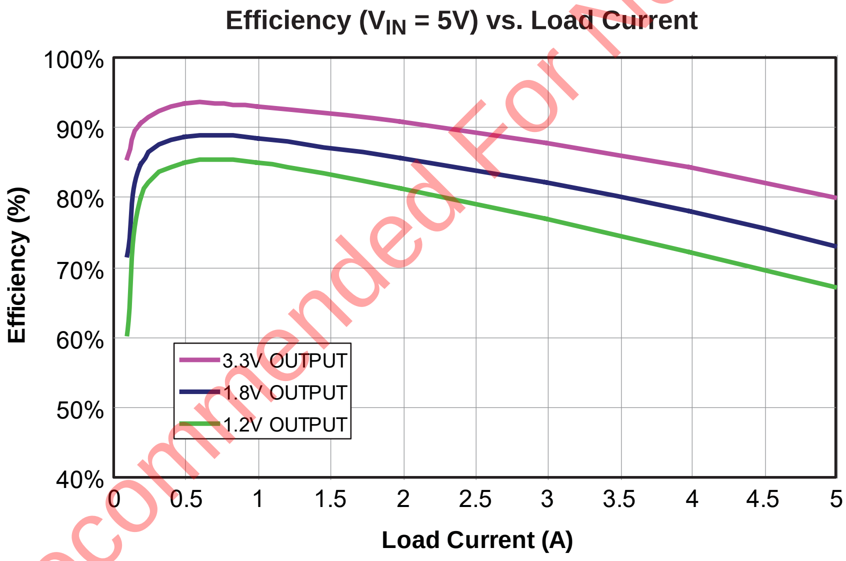


Short Circuit Recovery



Efficiency


Efficiency (V_{IN} = 12V) vs. Load Current
100%
90%
80%
70%
60%
50%
40%
Efficiency (%)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Load Current (A)
5V OUTPUT
3.3V OUTPUT
1.8V OUTPUT
1.2V OUTPUT


Efficiency (V_{IN} = 5V) vs. Load Current
100%
90%
80%
70%
60%
50%
40%
Efficiency (%)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Load Current (A)
3.3V OUTPUT
1.8V OUTPUT
1.2V OUTPUT

Detailed Description

The AOZ1036 is a current-mode step down regulator with integrated high-side PMOS switch and a low-side NMOS switch. It operates from a 4.5V to 18V input voltage range and supplies up to 5A of load current. Features include enable control, Power-On Reset, input under voltage lockout, output over voltage protection, active high power good state, fixed internal soft-start and thermal shut down.

The AOZ1036 comes in both a 5x4 DFN-8 and an exposed pad SO-8 package.

Enable and Soft Start

The AOZ1036 has internal soft start feature to limit in-rush current and ensure the output voltage ramps up smoothly to regulation voltage. A soft start process begins when the input voltage rises to 4.1V and voltage on EN pin is HIGH. In soft start process, the output voltage is ramped to regulation voltage in typically 3ms. The 3ms soft start time is set internally.

The EN pin of the AOZ1036 is active high. Connect the EN pin to VIN if enable function is not used. Pull it to ground will disable the AOZ1036. Do not leave it open. The voltage on EN pin must be above 2V to enable the AOZ1036. When voltage on EN pin falls below 0.6V, the AOZ1036 is disabled. If an application circuit requires the AOZ1036 to be disabled, an open drain or open collector circuit should be used to interface to EN pin.

Steady-State Operation

Under steady-state conditions, the converter operates in fixed frequency and Continuous-Conduction Mode (CCM).

The AOZ1036 integrates an internal P-MOSFET as the high-side switch. Inductor current is sensed by amplifying the voltage drop across the drain to source of the high side power MOSFET. Output voltage is divided down by the external voltage divider at the FB pin. The difference of the FB pin voltage and reference is amplified by the internal transconductance error amplifier. The error voltage, which shows on the COMP pin, is compared against the current signal, which is sum of inductor current signal and ramp compensation signal, at PWM comparator input. If the current signal is less than the error voltage, the internal high-side switch is on. The inductor current flows from the input through the inductor to the output. When the current signal exceeds the error voltage, the high-side switch is off. The inductor current is freewheeling through the internal low-side N-MOSFET switch to output. The internal adaptive FET driver guarantees no turn on overlap of both high-side and low-side switch.

Comparing with regulators using freewheeling Schottky diodes, the AOZ1036 uses freewheeling NMOSFET to realize synchronous rectification. It greatly improves the converter efficiency and reduces power loss in the low-side switch.

The AOZ1036 uses a P-Channel MOSFET as the high-side switch. It saves the bootstrap capacitor normally seen in a circuit which is using an NMOS switch.

Switching Frequency

The AOZ1036 switching frequency is fixed and set by an internal oscillator. The practical switching frequency could range from 400kHz to 600kHz due to device variation.

Light Load Mode

The AOZ1036 includes is a Pulse-Skip architecture for Light Load operation, enabling increased efficiency during standby. Under Heavy Loads, the controller operates in a standard Synchronous Mode using the high-side PMOS as control FET and low-side NMOS as synchronous rectifier NMOS. During Light Loads, the controller automatically switches to a Non-Synchronous mode using the high-side PMOS as control FET and the integrated diode as freewheeling rectifier diode.

Output Voltage Programming

Output voltage can be set by feeding back the output to the FB pin by using a resistor divider network. In the application circuit shown in Figure 1. The resistor divider network includes R_1 and R_2. Usually, a design is started by picking a fixed R_2 value and calculating the required R1 with equation below.

$$V_O = 0.8 \times \left(1 + \frac{R_1}{R_2}\right)$$

Some standard value of R_1, R_2 and most used output voltage values are listed in Table 1 on the next page.

Table 1.

Vo (V)	R1 (kΩ)	R2 (kΩ)
0.8	1.0	Open
1.2	4.99	10
1.5	10	11.5
1.8	12.7	10.2
2.5	21.5	10
3.3	31.1	10
5.0	52.3	10

The combination of R1 and R2 should be large enough to avoid drawing excessive current from the output, which will cause power loss.

Protection Features

The AOZ1036 has multiple protection features to prevent system circuit damage under abnormal conditions.

Over Current Protection (OCP)

The sensed inductor current signal is also used for over current protection. Since the AOZ1036 employs peak current mode control, the COMP pin voltage is proportional to the peak inductor current. The COMP pin voltage is limited to be between 0.4V and 2.5V internally. The peak inductor current is automatically limited cycle by cycle.

When the output is shorted to ground under fault conditions, the inductor current decays very slow during a switching cycle because of $V_O = 0V$. To prevent catastrophic failure, a secondary current limit is designed inside the AOZ1036. The measured inductor current is compared against a preset voltage which represents the current limit, between 3.5A and 5.0A. When the output current is more than current limit, the high side switch will be turned off. The converter will initiate a soft start once the over-current condition disappears.

Power-On Reset (POR)

A power-on reset circuit monitors the input voltage. When the input voltage exceeds 4.1V, the converter starts operation. When input voltage falls below 3.7V, the converter will be shut down.

Thermal Protection

An internal temperature sensor monitors the junction temperature. It shuts down the internal control circuit and high side PMOS if the junction temperature exceeds 150ºC. The regulator will restart automatically under the control of soft-start circuit when the junction temperature decreases to 100ºC.

Application Information

The basic AOZ1036 application circuit is show in Figure 1. Component selection is explained below.

Input Capacitor

The input capacitor must be connected to the V_{IN} pin and PGND pin of AOZ1036 to maintain steady input voltage and filter out the pulsing input current. The voltage rating of input capacitor must be greater than maximum input voltage plus ripple voltage.

The input ripple voltage can be approximated by the equation below:

$$\Delta V_{IN} = \frac{I_O}{f \times C_{IN}} \times \left(1 - \frac{V_O}{V_{IN}}\right) \times \frac{V_O}{V_{IN}}$$

Since the input current is discontinuous in a buck converter, the current stress on the input capacitor is another concern when selecting the capacitor. For a buck circuit, the RMS value of input capacitor current can be calculated by:

$$I_{CIN\_RMS} = I_O \times \sqrt{\frac{V_O}{V_{IN}}\left(1 - \frac{V_O}{V_{IN}}\right)}$$

if we let *m* equal the conversion ratio:

$$\frac{V_O}{V_{IN}} = m$$

The relation between the input capacitor RMS current and voltage conversion ratio is calculated and shown in Figure 2 on the next page. It can be seen that when V_O is half of V_{IN}, C_{IN} is under the worst current stress. The worst current stress on C_{IN} is $0.5 \times I_O$.

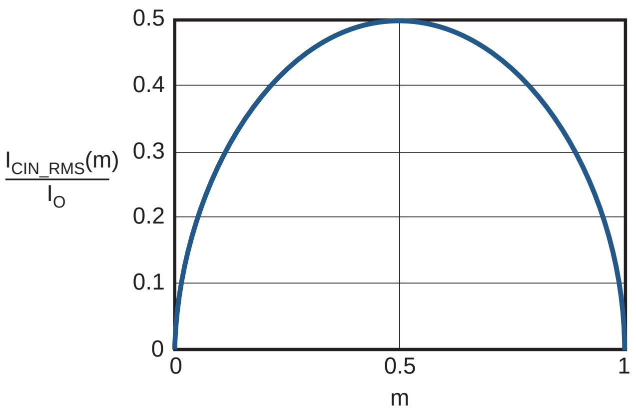


Figure 2. I_{CIN} vs. Voltage Conversion Ratio

For reliable operation and best performance, the input capacitors must have current rating higher than I_{CIN_RMS} at worst operating conditions. Ceramic capacitors are preferred for input capacitors because of their low ESR and high current rating. Depending on the application circuits, other low ESR tantalum capacitor may also be used. When selecting ceramic capacitors, X5R or X7R type dielectric ceramic capacitors should be used for their better temperature and voltage characteristics. Note that the ripple current rating from capacitor manufactures are based on certain amount of life time. Further de-rating may be necessary in practical design.

Inductor

The inductor is used to supply constant current to output when it is driven by a switching voltage. For given input and output voltage, inductance and switching frequency together decide the inductor ripple current, which is:

$$\Delta I_L = \frac{V_O}{f \times L} \times \left(1 - \frac{V_O}{V_{IN}}\right)$$

The peak inductor current is:

$$I_{Lpeak} = I_O + \frac{\Delta I_L}{2}$$

High inductance gives low inductor ripple current but requires larger size inductor to avoid saturation. Low ripple current reduces inductor core losses. It also reduces RMS current through inductor and switches, which results in less conduction loss. Usually, peak to peak ripple current on inductor is designed to be 20% to 30% of output current.

When selecting the inductor, make sure it is able to handle the peak current without saturation even at the highest operating temperature.

The inductor takes the highest current in a buck circuit. The conduction loss on inductor need to be checked for thermal and efficiency requirements.

Surface mount inductors in different shape and styles are available from Coilcraft, Elytone and Murata. Shielded inductors are small and radiate less EMI noise. But they cost more than unshielded inductors. The choice depends on EMI requirement, price and size.

Output Capacitor

The output capacitor is selected based on the DC output voltage rating, output ripple voltage specification and ripple current rating.

The selected output capacitor must have a higher rated voltage specification than the maximum desired output voltage including ripple. De-rating needs to be considered for long term reliability.

Output ripple voltage specification is another important factor for selecting the output capacitor. In a buck converter circuit, output ripple voltage is determined by inductor value, switching frequency, output capacitor value and ESR. It can be calculated by the equation below:

$$\Delta V_O = \Delta I_L \times \left(ESR_{CO} + \frac{1}{8 \times f \times C_O}\right)$$

where;

C_O is output capacitor value, and

ESR_{CO} is the Equivalent Series Resistor of output capacitor.

When low ESR ceramic capacitor is used as output capacitor, the impedance of the capacitor at the switching frequency dominates. Output ripple is mainly caused by capacitor value and inductor ripple current. The output ripple voltage calculation can be simplified to:

$$\Delta V_O = \Delta I_L \times \frac{1}{8 \times f \times C_O}$$

If the impedance of ESR at switching frequency dominates, the output ripple voltage is mainly decided by capacitor ESR and inductor ripple current. The output ripple voltage calculation can be further simplified to:

$$\Delta V_O = \Delta I_L \times ESR_{CO}$$

For lower output ripple voltage across the entire operating temperature range, X5R or X7R dielectric type of ceramic, or other low ESR tantalum are recommended to be used as output capacitors.

In a buck converter, output capacitor current is continuous. The RMS current of output capacitor is decided by the peak to peak inductor ripple current. It can be calculated by:

$$I_{CO\_RMS} = \frac{\Delta I_L}{\sqrt{12}}$$

Usually, the ripple current rating of the output capacitor is a smaller issue because of the low current stress. When the buck inductor is selected to be very small and inductor ripple current is high, output capacitor could be overstressed.

External Schottky Diode for High Input Operation

When V_{IN} is higher than 16V, an external 1A schottky diode is required between LX and PGND for proper operation.

Loop Compensation

The AOZ1036 employs peak current mode control for easy use and fast transient response. Peak current mode control eliminates the double pole effect of the output L&C filter. It greatly simplifies the compensation loop design.

With peak current mode control, the buck power stage can be simplified to be a one-pole and one-zero system in frequency domain. The pole is dominant pole can be calculated by:

$$f_{P1} = \frac{1}{2\pi \times C_O \times R_L}$$

The zero is a ESR zero due to output capacitor and its ESR. It is can be calculated by:

$$f_{Z1} = \frac{1}{2\pi \times C_O \times ESR_{CO}}$$

where;

C_O is the output filter capacitor,

R_L is load resistor value, and

ESR_{CO} is the equivalent series resistance of output capacitor.

The compensation design is actually to shape the converter control loop transfer function to get desired gain and phase. Several different types of compensation network can be used for the AOZ1036. For most cases, a series capacitor and resistor network connected to the COMP pin sets the pole-zero and is adequate for a stable high-bandwidth control loop.

In the AOZ1036, FB pin and COMP pin are the inverting input and the output of internal error amplifier. A series R and C compensation network connected to COMP provides one pole and one zero. The pole is:

$$f_{P2} = \frac{G_{EA}}{2\pi \times C_C \times G_{VEA}}$$

where;

G_{EA} is the error amplifier transconductance, which is 200 x 10^{-6} A/V,

G_{VEA} is the error amplifier voltage gain, which is 500 V/V, and

C_C is compensation capacitor in Figure 1.

The zero given by the external compensation network, capacitor C_C and resistor R_C, is located at:

$$f_{Z2} = \frac{1}{2\pi \times C_C \times R_C}$$

To design the compensation circuit, a target crossover frequency f_C for close loop must be selected. The system crossover frequency is where control loop has unity gain. The crossover is the also called the converter bandwidth. Generally a higher bandwidth means faster response to load transient. However, the bandwidth should not be too high because of system stability concern. When designing the compensation loop, converter stability under all line and load condition must be considered.

Usually, it is recommended to set the bandwidth to be equal or less than 1/10 of switching frequency. The AOZ1036 operates at a frequency range from 400kHz to 600kHz. It is recommended to choose a crossover frequency equal or less than 40kHz.

$$f_C = 40kHz$$

The strategy for choosing R_C and C_C is to set the cross over frequency with Rc and set the compensator zero with C_C. Using selected crossover frequency, f_C, to calculate R_C:

$$R_C = f_C \times \frac{V_O}{V_{FB}} \times \frac{2\pi \times C_C}{G_{EA} \times G_{CS}}$$

where;

f_C is desired crossover frequency. For best performance, f_C is set to be about 1/10 of switching frequency,

V_{FB} is 0.8V,

G_{EA} is the error amplifier transconductance, which is 200 x 10^{-6} A/V, and

G_{CS} is the current sense circuit transconductance, which is 6.68 A/V.

The compensation capacitor C_C and resistor R_C together make a zero. This zero is put somewhere close to the dominate pole f_{p1} but lower than 1/5 of selected crossover frequency. C_C can is selected by:

$$C_C = \frac{1.5}{2\pi \times R_C \times f_{P1}}$$

The equation above can also be simplified to:

$$C_C = \frac{C_O \times R_L}{R_C}$$

An easy-to-use application software which helps to design and simulate the compensation loop can be found at www.aosmd.com.

Thermal Management and Layout Consideration

In the AOZ1036 buck regulator circuit, high pulsing current flows through two circuit loops. The first loop starts from the input capacitors, to the VIN pin, to the LX pin, to the filter inductor, to the output capacitor and load, and then return to the input capacitor through ground. Current flows in the first loop when the high side switch is on. The second loop starts from inductor, to the output capacitors and load, to the low side NMOSFET. Current flows in the second loop when the low side NMOSFET is on.

In PCB layout, minimizing the two loops area reduces the noise of this circuit and improves efficiency. A ground plane is strongly recommended to connect input capacitor, output capacitor, and PGND pin of the AOZ1036.

In the AOZ1036 buck regulator circuit, the major power dissipating components are the AOZ1036 and the output inductor. The total power dissipation of converter circuit can be measured by input power minus output power.

$$P_{total\_loss} = V_{IN} \times I_{IN} - V_O \times I_O$$

The power dissipation of inductor can be approximately calculated by output current and DCR of inductor.

$$P_{inductor\_loss} = I_O^2 \times R_{inductor} \times 1.1$$

The actual junction temperature can be calculated with power dissipation in the AOZ1036 and thermal impedance from junction to ambient.

$$T_{junction} = (P_{total\_loss} - P_{inductor\_loss}) \times \Theta_{JA}$$

The maximum junction temperature of AOZ1036 is 150ºC, which limits the maximum load current capability. Please see the thermal de-rating curves for maximum load current of the AOZ1036 under different ambient temperature.

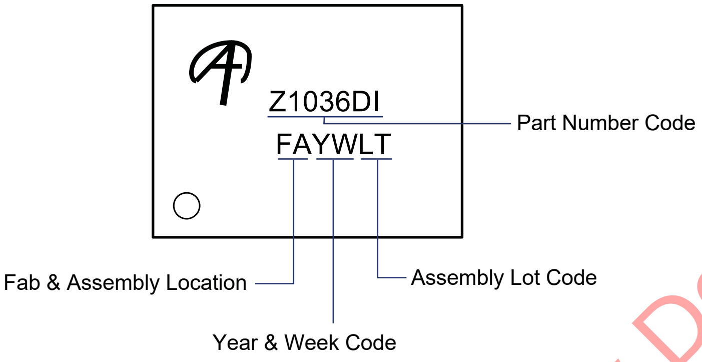
The thermal performance of the AOZ1036 is strongly affected by the PCB layout. Extra care should be taken by users during design process to ensure that the IC will operate under the recommended environmental conditions.

Several layout tips are listed below for the best electric and thermal performance.

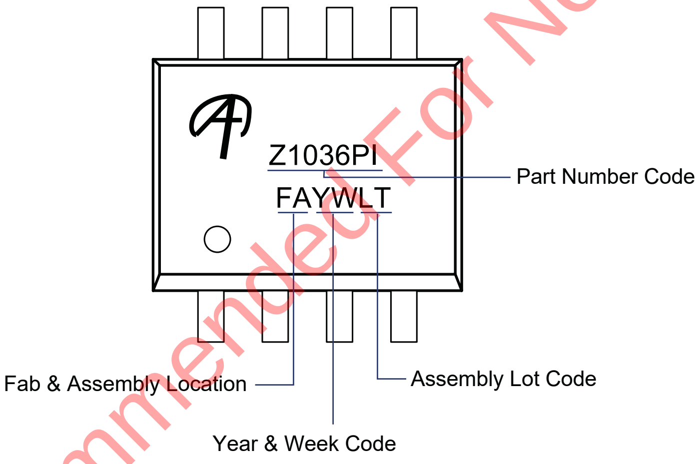
1. The LX pins are connected to internal PFET and NFET drains. They are low resistance thermal conduction path and most noisy switching node. Connected a large copper plane to LX pin to help thermal dissipation.
2. Do not use thermal relief connection to the VIN and the PGND pin. Pour a maximized copper area to the PGND pin and the VIN pin to help thermal dissipation.
3. Input capacitor should be connected to the VIN pin and the PGND pin as close as possible.
4. A ground plane is preferred. If a ground plane is not used, separate PGND from AGND and connect them only at one point to avoid the PGND pin noise coupling to the AGND pin.
5. Make the current trace from LX pins to L to Co to the PGND as short as possible.
6. Pour copper plane on all unused board area and connect it to stable DC nodes, like VIN, GND or VOUT.
7. Keep sensitive signal trace far away from the LX pins.

Part Marking

5x4 DFN-8



Exposed Pad SO-8



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